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MERCHANT SHIPPING EXPERIMENTS ON STEEL.

Memorandum issued by the Board of Trade for the use of their Surveyors, containing the remarks of the Engineer Surveyor-in-Chief and his Assistants, upon the use of Mild Steel, manufactured by the Steel Company of Scotland, together with an Appendix showing the tabular Results of Experiments made with regard thereto.

Preſented to both Houſes of Parliament by Command of Her Majeſty.

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Experiments on Steel.

REMARKS of the ENGINEER SURVEYOR in CHIEF, and his ASSISTANTS, respecting the MILD STEEL manufactured by the STEEL COMPANY of SCOTLAND; also TABULAR RESULTS of TESTS.

STEEL as a material for ship building and boiler-making has for years been used to some extent. Its general introduction has, however, been delayed owing to the fact that it could not be regarded as invariably reliable, as it frequently occurred that amongst a batch of plates, the greater part of which had been considered satisfactory, a proportion was found not to possess the properties required, and to fail in the ship yard or boiler yard. It has been argued, and probably with some truth, that in some cases a prejudice was unjustly created against the use of steel owing to its failure under treatment which should never have been applied to it. The mild steel, which is now being introduced, is of a softer and more ductile character, and much better able to bear the manipulation to which it is subjected, still in some respects it requires special care in its treatment.

Steel is mainly distinguished from wrought iron by its property of becoming harder and more brittle when raised to a red heat and cooled suddenly in water. This peculiarity is attributed to the former containing a greater amount of carbon than the latter in which generally only a trace of it is found. Steel which contains about 1 per cent. of carbon possesses a very high tensile strength; takes a high degree of temper when heated and cooled suddenly in water, but being brittle in character is unsuited for ship-building and boiler making, both on account of its uncertainty in withstanding the necessary operations in the course of manufacture, and also because of the danger of employing a brittle material to withstand the strains to which steam boilers and the hulls of vessels are continually exposed. In the mild steel under consideration the amount of carbon is very small, and manufacturers consider as a proof of its suitability for the purposes mentioned that it will when heated and cooled suddenly in water bear bending double. The fact of the material, when treated as described, not taking the degree of hardness usual with ordinary steel, has led some persons to doubt the advisability of the term "steel" being applied to it, upon the ground that it is only a purer form of iron. The experience which has been gained with it has, however, shown that it differs in many respects from wrought iron, and that the term "mild "steel" in the absence of a better, which has not yet been suggested, is perhaps the most suitable which can be used.

Upon the Board of Trade being requested by the Steel Company of Scotland to sanction the steel manufactured by them in the construction of ships, machinery, and boilers passed by the Board's officers, they were requested to undertake such a series of tests as would enable the advisers of the Board of Trade to judge of its suitability for the above purposes, and also its ability to withstand without undue injury the manipulation to which it would be exposed.

The Company very readily acquiesced in the justness of the request, and forwarded for testing a set of plates, ¼, ½, ¾, and 1 inch thick; they also caused to be constructed a set of experimental boxes of different thicknesses of steel plate to represent the flat surfaces of steam boilers. These have been burst by hydraulic pressure, and a large amount of valuable information gained respecting the strength of such surfaces when formed of steel plates.

Having visited the works of the Steel Company of Scotland when every facility was given for inspection, it may be interesting if a few particulars are stated respecting them previous to giving the results of the valuable series of experiments which have been made upon steel manufactured there. The Company was originated about the year 1872, and at Newton, near Glasgow, extensive works were erected for the manufacture of steel by the Siemens Martin process. They are provided with machinery and tools of the most recent and improved description for the manufacture of plates, rails, forgings, &c. The melting shop has been erected to cover over 30 steel melting furnaces, 18 of which, with the necessary gas producers, &c. have been started, and are said to be capable of producing about 65,000 tons of steel per annum. The rail mill driven by compound reversing engines can roll direct from the ingot about 40,000 tons of rails of ordinary sections per annum, and is also adapted to the rolling of heavy angles, T bulbs, beams, &c.

Three plate mills now at work at Newton, driven by reversing engines, can roll about 25,000 tons of average plates per annum. A 14-inch bar mill is kept at work on light rails, angles, &c., whilst three 8-ton hammers and one 3-ton hammer are employed for forging slabs, billets, &c. A large foundry has been erected for making steel castings, and in addition to workshops and smithy another large iron foundry has been erected for repairing purposes, and for casting the rolls and ingot moulds required for the works.

I am informed that the Company have recently purchased the Blochairn Works, Glasgow, where furnaces are, it is stated, to be constructed equal to the production of 80,000 tons of ingot per annum.

The re-heating and annealing furnaces are heated by gas, and the present consumption of coal and dross at the works for gas making and steam power is stated to exceed 100,000 tons per annum.

The Company prefer, instead of running direct from the blast furnace, to use selected brands of hæmatite pig iron, good steel and iron scrap, and pure iron ores, ferro-manganese being added when the charge is being tapped. A charge of ordinary steel takes from seven to nine hours, and the length of the operation gives those in charge a good opportunity for testing the metal during the various stages of manufacture, and tends to ensure a uniform make of steel of the desired quality. The Company have directed special attention to the production of mild steel for ship-building and boiler making, and have been doing all in their power by undertaking the extensive series of experiments which will shortly be considered, to show that a suitable and uniformly reliable quality of steel can be made for these purposes. It is stated that in making mild steel for plates, the best brands of Bessemer pig iron are used, and the charge is frequently tested when in the furnace as well as by chemical analysis. When the steel is being run into the moulds a small test ingot is cast, which besides being tested chemically is rolled into a plate, pieces of which are tested by bending. The tensile strength and elongation of the steel are also tested in a machine erected at the works for this purpose. If the charge is found right for the particular purpose required, the ingots are marked with the number of the charge, and the quality of the steel. The ingots are afterwards hammered into slabs from which the plates are rolled, and to ensure against risk of mistakes a test piece is cut from each plate and angle, and subjected to the bending and tempering test.

The experiments made, and the attention bestowed by the Company in endeavouring to arrive at the best possible quality of steel for shipbuilding and boiler making has resulted in securing a greater amount of confidence amongst shipbuilders and engineers, and this is more especially the case where the steel has been actually used.

Tables 1 to 19 give the results of tests which Mr. Kirkaldy was requested to make and are exactly as received. In the body of this report some particulars deduced from Mr. Kirkaldy's tables are given which will, it is hoped, be found of use when considering the subject.

Respecting the Experiments made to ascertain the Elastic and Ultimate Stresses and Ductility of Steel Plates made by the Steel Company of Scotland.

Tables 1 and 13 contain the results of testing for tensile strength and elongation 48 specimens cut from 12 steel plates, ¼, ½, ¾, and 1 inch thick. Half the number were cut lengthway of the plate and half crossway. The separation of the strips from the plate was in every case done by the planing or slotting machine, and not by the shearing machine, so as to avoid any disturbance of the texture of the material.

The following summary contains mean results taken from tables 1 and 13 :—

Thickness of Plate.	Mean Elastic Stress per square inch.		Mean Ultimate Stress per square inch.		Mean Ratio of Elastic to Ultimate.	
	Lengthway.	Crossway.	Lengthway.	Crossway.	Lengthway.	Crossway.
inch.	tons.	tons.	tons.	tons.	per cent.	per cent.
¼	19·0	19·1	31·0	31·4	61	60
½	15·8	15·7	28·9	28·6	54	55
¾	15·8	15·6	29·5	29·1	53	53
1	14·9	14·8	28·0	28·0	53	52
Total mean	16·3	16·3	29·3	29·2	55	55

The term Ultimate Stress is always understood to mean the stress which being gradually applied will break the specimen; but as there is by no means the same unanimity respecting the meaning to be attached to the term "Elastic Stress" it may, in order to prevent misunderstanding, be well to quote some remarks made by Mr. Kirkaldy, by whom it is employed. In his published report on the Fagersta Steel he gives examples of his method of ascertaining the elastic stress or elastic limit of the material under test. The following table is extracted from one in the above report :—

ABSTRACT from TABLE giving DETAILED RESULTS of EXPERIMENTS upon FAGERSTA STEEL PLATE to ASCERTAIN the INCREMENTS of LENGTH with CORRESPONDING SETS under a GRADUALLY INCREASED PULLING STRESS.

Description.	Marked.	Test No.	Thickness.	Stress in pounds per square inch. Increments and sets, inch.																					Stress.		Ratio of elastic to ultimate.
				10,000.	12,000.	14,000.	16,000.	18,000.	20,000.	22,000.	24,000.	26,000.	28,000.	30,000.	32,000.	34,000.	36,000.	38,000.	40,000.	42,000.	44,000.	46,000.	48,000.	50,000.	Elastic per square inch.	Ultimate per square inch.	
Unannealed. ¶	1.¼	1,058	·245	·027 set	·034	·041	·048	·056	·064 ·000	·072	·079	·086	·094	·102 ·006	·110	·118	·133 —	·151	·428 ·311	1·84	2·70	3·26	4·15	5·34	35,600	54,140	65·7
	1.⅜	1,062	·380	·030 set	·038	·046	·054	·062	·070 ·004	·078	·086	·104 —	·204	1·75 1·64	2·49	3·07	3·83	4·63	5·40 5·20	6·56	8·05	10·45	14·55	—	25,400	48,925	51·9
	1.½	1,066	·500	·028 set	·034	·040	·046	·052	·058 ·000	·064	·070	·077	·130 —	·648 ·500	1·92	2·45	3·08	3·61	4·59 4·46	5·55	7·00	8·55	11·00	14·15	27,500	50,160	54·8

He remarks as follows :—"Running the eye along the lines
" it will be noticed that the specimens extend at a comparatively
" uniform and slightly increasing rate at each addition of
" 2,000 lbs. per square inch to the load, until a certain point is
" reached, when the rates of extension more or less rapidly
" increase, which point indicates the elastic strength of the
" material. A short line is placed under the figures in this table
" to call attention, at a glance, to where the increments cease to
" be uniform, and where it is found that the elasticity of the
" specimen has become impaired."

It will be observed that in some cases a set is recorded at a lower stress than the Elastic Stress, so that the term as applied in these tables does not mean, as understood by some persons, the stress at which a permanent set takes place.

By the term "Elastic Stress" is sometimes understood the stress or load which, although not causing fracture at once, will do so if repeated a sufficient number of times. What relation there may be between the above stress, and the Elastic Stress as recorded in Mr. Kirkaldy's tables, it is impossible to say without further experiments. Although a matter of the deepest interest to engineers and shipbuilders, few, if any, experiments have been made to settle this question as regards iron and steel, a fact much to be regretted, as the information to be obtained would doubtless be most valuable, and possibly lead to great economy in the application of those metals.

Referring to the summary we see that with the exception of the ½ inch plates there is a gradual increase in the ultimate stress with the reduction of thickness, the ultimate stress of the ¼ inch plates exceeding that of the 1 inch by about 10 per cent. A similar increase occurs with the elastic stress, which, in the case of the ¼ inch plates, exceeds that of the 1 inch by about 27 per cent. The increase of the elastic stress with the reduction of thickness is thus more marked than the ultimate. The above remarks are made regarding the lengthway specimens, but the values for the crossway are not very different.

There is also a steady increase in the ratio of the elastic to the ultimate stress as the thickness is reduced, that of the ¼ inch plate having a large excess over the others. In the ¼ inch lengthway specimens it exceeds that of the 1 inch by about 15 per cent. The increase in the elastic and ultimate stresses with the reduction of thickness is probably due to some extent to the greater amount of working which the material receives in the process of rolling; it is, however, not likely to be wholly due to this cause.

Thickness of Plate.	Ultimate Extension in 10 inches.		Contraction of area at fracture.	
	Lengthway.	Crossway.	Lengthway.	Crossway.
	per cent.	per cent.	per cent.	per cent.
¼ inch.	23·5	21·2	46·0	39·9
½ "	29·8	28·9	53·2	40·9
¾ "	29·2	26·6	46·8	38·3
1 "	30·6	25·6	50·4	42·4
Total mean	28·2	25·5	49·1	40·3

The ultimate extensions of the ¼ inch specimens are considerably less than with the thicker plates ; this fact, together with the lower contraction of area at fracture, appears to show that they are of a rather harder quality. Even if made from the same charge there is possibly a liability to a greater degree of hardness in the very thin plates owing to their being more rapidly cooled in the process of annealing, unless it is performed under exceptionally favourable conditions.

The ultimate stresses of the ¼, ½, ¾, and 1 inch plates lengthway and crossway are respectively almost equal, and the same also occurs with the elastic stresses. It is worthy of note that, although the mean elastic and ultimate stresses lengthway and crossway are almost identical, the mean contraction of area at fracture, and ultimate extension lengthway, are greater than crossway, showing that the ductility of the material in the former direction is greater than in the latter.

The fact of the mean contraction of area at fracture of the lengthway and crossway specimens being 49·1 and 40·3 per cent. respectively, indicates the possession of great ductility, and in this respect the steel compares most favourably with both iron ship and boiler plates. The following tables give the mean results of testing a number of iron ship plates of various brands, the specimens being cut lengthway and unperforated :—

Results of Testing ordinary Iron Ship Plates.

Thickness of Plates.	Mean Ultimate Stress per square inch.	Mean Contraction of Area at Fracture.	Mean Ultimate Extension in 10 inches.
	tons.	per cent.	per cent.
¼ inch - - -	24·00	6·8	7·0
½ " - - -	22·62	4·7	6·7
¾ " - - -	19·42	4·8	3·6
Total mean - -	22·01	5·4	5·7

The results of testing a large number of ordinary iron boiler plates of different brands are as follows, the specimens being unperforated :—

Results of Testing ordinary Iron Boiler Plates.						
Thickness of Plates.	Lengthway.			Crossway.		
	Mean Ultimate Stress per Square Inch	Mean Contraction of Area at Fracture.	Mean Ultimate Extension in 10 Inches.	Mean Ultimate Stress per square Inch.	Mean Contraction of Area at Fracture.	Mean Ultimate Extension in 10 Inches.
	tons.	per cent.	per cent.	tons.	per cent.	per cent.
½ inch -	21·20	12·91	9·0	19·03	4·28	2·7
¾ ,, -	21·40	13·30	10·1	18·67	5·08	3·8
1 ,, -	20·86	13·0	9·8	17·74	3·87	3·1
Total mean	21·15	13·07	9·6	18·48	4·41	3·2

Comparing these results with those obtained with the ship plates the greater uniformity of the boiler plates of all thicknesses will be remarked. The larger contraction of area at fracture and ultimate extension of the iron boiler plates also indicate the higher degree of ductility which they possess as compared with the iron ship plates.

The following summary contains the mean results of the two last tables, also the results of testing the steel plates, together with the mean results published by Mr. Kirkaldy respecting a number of Yorkshire wrought-iron plates tested by him :—

Description.	Thickness of Plates.	Lengthway.			Crossway.		
		Mean Ultimate Stress per Square Inch.	Mean Contraction of Area at Fracture.	Mean Ultimate Extension in 10 Inches.	Mean Ultimate Stress per Square Inch.	Mean Contraction of Area at Fracture.	Mean Ultimate Extension in 10 Inches.
	inch.	tons.	per cent.	per cent.	tons.	per cent.	per cent.
Iron Ship Plates.	¼, ½, ¾	22·01	5·4	5·7			
Iron Boiler Plates, ordinary quality.	½, ¾, 1	21·15	13·07	9·6	18·48	4·41	3·2
Yorkshire Wrought Iron Plates.	⅜ ½, ⅝	21·3	20·6	16·7	20·3	14·7	11·2
Steel plates of Steel Company of Scotland.	¼, ½, ¾, 1	29·3	49·1	28·2	29·2	40·3	25·5

The thicknesses of the plates experimented upon are not identical in the different classes, but the results for the present purpose of comparison are not practically affected thereby. Comparing the steel with the iron the ultimate stress of the former is about 36 per cent. greater than the mean of the latter. The contraction of area at fracture of the steel largely exceeds that of the different irons. In the case of the steel lengthway, it is 49·1 per cent. against 20·6 per cent. for the Yorkshire iron, 13·07 per cent. for the ordinary iron boiler plate, and 5·4 per cent. for the iron ship plate. As the contraction of area at fracture is a guide to the ductility of materials it will at once be understood to how large an extent the ductility of the steel plates exceeds that of the iron, especially the ordinary boiler and ship plates.

Another fact worthy of attention is that whilst in the case of iron plates the ultimate stress and contraction of area at fracture crossway are less than lengthway rendering it always desirable to apply the principal strains lengthway of the iron plates, this does not appear to apply to so great an extent with the steel tested, for the ultimate stresses in both directions are almost identical and the ductility crossway is not much less than lengthway.

It will have been observed that the mean ultimate stress of some of the common ship plates is greater than that of either of the other descriptions of iron plate. This is by no means uncommon, a high ultimate stress being often found to occur with hard brittle plates. The more ductile plates are however preferred even with a lower ultimate stress, because of the brittle plates suffering more from punching and being liable to snap suddenly.

When a brittle material is tested to destruction there is little or no indication of approaching fracture, the specimen breaking suddenly. If, however, this mild steel is watched whilst under pulling stress it is seen that a considerable extension and reduction of cross section takes place before the greatest stress is reached, thereby proving that the material is increased in strength by the process of drawing out, just as steel and some other kinds of wire are found to be stronger than the material from which drawn.

The degree of ductility this steel has been shown to possess is a quality which renders it very suitable for use in shipbuilding and boiler work. It is indeed difficult to over estimate its importance, as unless injured in the ship yard or boiler yard, the material is thereby endowed with a great safeguard against sudden failure. In the event of overstraining of either a ship or boiler, instead of sudden failure occuring, as would be the case if made of a brittle material, warning of danger would be given by leakage at the riveted joints, owing to the reduction of section of the plate between the rivet holes, and the consequent elongation of the rivet holes. The extent to which this occurs will be considered further on when dealing with the perforated specimens.

It has been remarked in some quarters that the great ductility of soft steel is a disadvantage. This opinion would appear to have been expressed owing to a belief that its elastic stress is so low as to give the material very little advantage over iron for sustaining loads. This, however, is evidently erroneous; the results of the experiments under consideration show that the elastic stresses of the steel lengthway and crossway are about 55 per cent. of the ultimate. We find by referring to the published reports of Mr. Kirkaldy respecting the Essen and Yorkshire wrought-iron plates, as follows:—

Thickness.	Ratio of Elastic to Ultimate Stress.			
	Essen Wrought Iron Plates.		Yorkshire Wrought Iron Plates.	
	Lengthway.	Crossway.	Lengthway.	Crossway.
	per cent.	per cent.	per cent.	per cent.
⅜ inch - -	54·2	56·0	58·5	62·4
½ „ - -	48·9	50·2	58·8	62·3
⅝ „ - -	51·0	51·6	58·1	59·6
Mean -	51·3	52·6	58·4	61·4

So that in the steel plates in question the ratio of the elastic to the ultimate stress, viz., about 55 per cent., stands about midway between that of the above two high class irons, although the ductility of the steel is in excess of that of the Essen plates, and more so of the Yorkshire plates.

Summarising the last three columns in tables 1 and 13 respecting the lengthway specimens we get as follows:—

Thickness of Plates.	Mean Extension Set in 10 Inches.		
	At 50,000 lbs. per Square Inch.	At 60,000 lbs. per Square Inch.	Ultimate.
	per cent.	per cent.	per cent.
¼ inch. - -	1·50	6·36	23·5
½ „ - -	4·80	10·9	29·8
¾ „ - -	4·99	9·62	29·2
1 „ - -	5·73	13·25	30·6
Mean - -	4·25	10·03	28·2

Owing to the lower ultimate stress of the Yorkshire plates we are unable to compare the extension sets with those of the steel plates at stresses of 50,000 lbs. and 60,000 lbs. per square inch. At 30,000 and 40,000 lbs. per square inch the mean extension sets of the ⅜, ½, and ⅝ inch Yorkshire plates are respectively 0·65 and 5·43 per cent. The above stresses are respectively 62 and 83 per cent. of the mean ultimate stress. Tables

1 and 13 do not contain the extension sets of the steel plates at these particular stresses. Mr. Kirkaldy was written to respecting the extension set at the latter, but stated that it was not ascertained. Fortunately we have the means of comparison in the case of the specimens prepared by Mr. Halket from steel plates supplied by the Steel Company of Scotland, and which will be referred to in the next section. From the results obtained by testing them, it was found that at 62 and 83 per cent. of the ultimate stress the mean extension sets in 10 inches were respectively 0·47 and 5·9 per cent., the extension sets for the Yorkshire wrought-iron plates at the same proportion of the ultimate stress being as stated above 0·65 and 5·43 per cent. respectively. We thus see that although the *ultimate* extension set of the steel largely exceeds that of the Yorkshire iron plates, the extension set of the former at 62 per cent. of the ultimate is only about three-fourths of that with the latter, but at 83 per cent. of the ultimate is slightly greater.

Probably few practical engineers or shipbuilders could be found who would seriously assert that the above high class iron plates are unsuitable for employment in the construction of ships, as well as boilers, if considerations of expense did not prevent their general use. As the extension set of the steel compares so favourably with that of high-class iron plates at the same proportion of the ultimate stress, its suitability for shipbuilding and boiler-making is thus amply proved by the experiments so far as ductility is concerned.

Continuing the examination of the summary we find that whilst at the mean *ultimate* stress of 65,632 lbs. per square inch there is an ultimate extension of 28·2 per cent., yet at a slightly lower stress of 60,000 lbs. or about 90 per cent. of the ultimate the extension set is only about one-third of the ultimate extension. The remainder thus takes place during the application of the last 10 per cent. of the ultimate stress. It should not be forgotten, as has been pointed out by Mr. Kirkaldy in his published works, that ultimate extension consists of two parts, (1) general stretching, and (2) stretching near the point of fracture which is due to contraction of area. It is evident that as with other soft metals the ultimate extension of mild steel consists largely of the latter.

RESPECTING the RESULTS of EXPERIMENTS made to ascertain the EFFECTS produced upon the TENSILE STRENGTH, &c. of STEEL PLATES by Drilled Holes, Punched Holes, Holes bored after Punching, and by Annealing the Plates after Punching.

Tables Nos. 2, 3, 4, and 5 contain the results of experiments made by Mr. Kirkaldy to determine the ultimate tensile stresses of steel plates (1) drilled, (2) punched, and (3) punched and afterwards annealed; two specimens of each kind, ¼, ½, ¾, and 1 inch thick being tested. In order to obviate the uncertainty which frequently exists with specimens of slight width, plates 12 inches wide were used in each case, the holes being arranged as shown in the sketches at the heads of the tables. The ends of the specimens were held in strong steel plates by tightly fitting pins in order to ensure the stresses being fairly applied. The drilling of the specimens was done by Mr. Kirkaldy, and the punching and annealing by Messrs. J. and G. Rennie, marine engineers. They were requested to punch the plates the same size as the drilled holes, and to use their usual punches and dies in order to ensure average results being obtained. The process of annealing adopted in the case of the plates so treated was to heat them to a dull red heat and cover them with ashes until cold.

Mr. Kirkaldy has given in his report the stresses per square inch of gross area at holes. Summarising them for convenience of reference we have as follows :—

Specimens.	Ultimate Stress per Square Inch of Gross Area at Holes.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	tons.	tons.	tons.	tons.
Drilled - -	21·9	19·6	19·65	18·3
Punched -	19·3	16·65	15·8	13·45
Punched and annealed	20·15	18·55	18·7	17·8

These stresses are calculated with reference to the total sectional area of the plate, including therein the part which is removed by perforation, and enable a comparison to be made between the actual stresses sustained by the different plates per inch run. It will be seen that the punched plates of each thickness stand a considerably lower stress than those which were drilled, or punched and afterwards annealed, and that the drilled plates stand a higher stress than those punched and afterwards annealed.

The calculation of the stresses per gross area has some obvious advantage when comparing punched with drilled plates. The stresses borne by the plates of different thicknesses in which the sizes of the holes differ, cannot, however, be compared thereby, so that the stresses upon the net section of plate between the holes have accordingly been calculated and are given below.

The metal punched out in the case of the punched specimens is considered as equivalent to parallel holes the diameter of small end; the reason of this will be given later on.

Specimen.	Mean Stress per Square Inch of Net Section between Holes.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	tons.	tons.	tons.	tons.
Drilled - -	36·21	32·44	31·64	29·42
Punched -	31·94	27·53	24·6	21·02
Punched and annealed.	33·41	30·75	30·05	27·82
Solid plates -	31·65	29·15	29·7	27·7

If the stresses are expressed in terms of the per-centage of strength of the unperforated plate the values stand thus:—

Specimen.	Stress per Square Inch of Net Section compared with the Solid Plate (= 100).			
	¼-inch.	½-inch.	¾-inch.	1 inch.
	per cent.	per cent.	per cent.	per cent.
Drilled - -	113·8	111·1	106·4	106·1
Punched -	101·0	94·2	82·5	75·8
Punched and annealed	105·6	105·6	101·0	100·3

The losses or gains as compared with the solid plate are as follows:—

Specimens.	Difference between the Ultimate Stress per square inch of Net Section of Perforated and Unperforated Plates.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Drilled - -	Gain 13·8	Gain 11·1	Gain 6·4	Gain 6·1
Punched - -	Gain 1·0	Loss 5·8	Loss 17·5	Loss 24·2
Punched and annealed	Gain 5·6	Gain 5·6	Gain 1·0	Gain 0·3

It will be observed that with the drilled plates there is a marked increase in the stress per square inch of net area between the holes over the stress per square inch of the solid plate, thus the ¼, ½,

¾, and 1 inch plates show respectively a mean increase of 13·8, 11·1, 6·4, and 6·1 per cent., the excesses becoming less as the thickness of the plate increases. As regards the plates which were punched and afterwards annealed, the ultimate stresses are respectively 5·6, 5·6, 1·0, and 0·3 per cent. greater than the stresses per square inch of the original plates. These results are far better than those obtained with the punched plates, but they are still less than those found with the drilled. It should be remarked that in some experiments which were made after these, and which will be referred to later, there was not so great a difference between the ultimate stresses of the drilled specimens, and those punched and afterwards annealed.

At first sight there appears to be something paradoxical in the idea that by drilling holes in a plate, the stress per square inch between the holes can be increased, but a similar result has frequently been found to occur when the length of a specimen over which stretching takes place is reduced by a narrow groove being planed or turned in it. It is probable that the stress per square inch of perforated mild steel plate between the holes would always be found greater than the stress per square inch of the solid plate were it not that the injury to the plate by punching is greater than the increase in ultimate stress arising from the form of the plate at the holes. Mr. Kirkaldy has referred to the effect which the form of a specimen exerts upon its ultimate stress in his work, "Experiments on Wrought Iron and Steel," and also in his report on the Essen and Yorkshire iron plates. In the latter are the following remarks which may be read with advantage, "The ultimate stress borne by a specimen is greatly affected "by the hardness or softness of the material and by the shape of "the specimen. The softer the material, the more rapidly does "its sectional area become reduced by the specimen stretching "and consequently in the amount of stress sustained. When the "breadth of a specimen is reduced to a minimum at one point, a "greater resistance is offered to its stretching than when formed "parallel for some distance; and as the stretching is checked, so "will also the contraction of area, and with it will be an increase "in the ultimate stress."

In the case of the plates with punched holes but not afterwards annealed, the stress of the ¼ inch plates per square inch of the net area between the holes is practically the same as that of the original plate. The injurious effects of punching are much more marked as the thickness increases, for in the case of the ½, ¾, and 1 inch plates the stress per square inch of the net area between the holes is 5·8, 17·5, and 24·2 per cent. respectively, less than the stress per square inch of the plate before punching.

Comparing the punched with drilled plates, there is a loss with the former due to the effects of punching of 11·79, 15·1, 22·2, and 28·5 per cent. of the stress of the drilled plates. These percentages really represent the injurious effects of punching upon the plate, and show how barbarous an instrument the punch is when mild steel is subjected to its action.

These results point conclusively to the almost absolute necessity of all steel plates being drilled, or the injurious effects of punching removed by annealing, or other means, unless a large portion of the strength of the steel is to be wasted. There is no doubt that when a plate is punched the metal in the immediate vicinity of the hole is put into a state of compression. This appears to arise to some extent, from the "punching" before it separates from the specimen being reduced to less than the thickness of the plate, and consequently exerting a pressure radially round the hole, which is resisted by the plate beyond the zone of compressed metal. The efficacy of annealing appears to depend upon the fact that whilst slowly cooling, the molecules re-arrange themselves and the local compression is reduced.

The recuperative power of annealing on the punched plates as the thickness increases is represented for the ¼, ½, ¾, and 1 inch plates by the per-centages 4·6, 11·4, 18·5, and 24·5, which are the differences between the per-centages for the punched plates, and those punched and afterwards annealed.

Taking from the last summary the differences between the per-centages of the drilled plates and those punched and afterwards annealed, we have 8·2, 5·5, 5·4, and 5·8 per cent. respectively for the ¼, ½, ¾, and 1 inch plates. A very interesting question thus presents itself, do these lower values arise from the lower ultimate stress of the plate, owing to the greater softness of the material caused by annealing, and to the reduced section caused by the taper holes in the punched and annealed plates, or do they represent the injury due to punching which annealing did not remove? The smaller elongation of the holes in the annealed specimens which will shortly be referred to does not however appear to indicate greater softness.

It is of the highest importance that annealing should be carefully done. It has been already stated that the specimens in this series which were annealed, were raised to a dull red heat and covered with ashes until cold. The results obtained can therefore only be considered to apply to this steel when the annealing is performed in this way. If it be performed carelessly or inefficiently, the results will most likely be very different from what have been mentioned, and the injury arising from punching may be little, if at all, removed. The results of some experiments subsequently made with some punched and annealed specimens with great care, and which will be referred to later, showed that the precise amount of advantage obtained in the series we have been considering may be somewhat modified.

In the Tables 2, 3, 4, and 5, under consideration, valuable information is afforded respecting the effects of the different treatment on the ductility of the steel, as shown by the elongation of the holes at ultimate stress.

The following summary contains the mean results :—

Specimens.	Elongation of Holes at Ultimate Stress.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Drilled - -	24·3	37·0	37·6	33·5
Punched -	11·7	18·5	11·1	4·3
Punched and annealed -	27·1	35·1	33·0	29·8

The elongation of the holes in the ¼-inch specimens is thus much less than in the ½, ¾, and 1 inch ; this is probably due to the greater hardness of the former, which has been already referred to.

Punching which has been proved so injuriously to affect the tensile strength of the steel plate is also seen to reduce the ductility in a very large degree, as shown by the reduced elongation of the punched holes as compared with the drilled, the mean elongation of the former being 11·4, and of the latter 33·1 per cent. The injurious effects of punching upon the tensile strength has been shown to be greatest with the thickest plates, and in them also the ductility of the material is seen by the smaller amount of elongation of the punched holes to be most reduced ; the elongation of the drilled holes in the ¾ and 1 inch plates which are 37·6 and 33·5 per cent. respectively, being reduced in the punched to 11·1 and 4·3 respectively, a much larger reduction than occurs with the ¼ and ½ inch plates.

Annealing, which so largely removes the injurious effects of punching upon the tensile stress, is also found to greatly restore the ductility, the elongation of the holes when the plates are annealed after punching, being not much less than the drilled.

The remarks which have been made in the former section, regarding the difference between the behaviour of brittle and ductile materials when tested to destruction, apply with great force also to the perforated plates. Those in which the holes are drilled, or those which are annealed after punching, break in the way described for ductile materials, whilst the ¾ and 1 inch punched plates which are considerably injured by punching, give little or no warning of approaching fracture.

From the results of the experiments there appears to be no doubt that in the event of the stress on either a ship or steam boiler constructed of this mild steel approaching a dangerous limit, warning would be given by leakage at the rivet holes if the holes were drilled, or the plates properly annealed after punching. The elongation of the punched holes has been shown to be so much less than of the drilled holes or the punched holes when the plates are afterwards annealed, and the punched specimens break so suddenly, that it is doubtful if warning would be given under similar circumstances.

A consideration of the appearance of the fractures of the different specimens is very interesting. Tables 1 and 13 show that the fractures of the unperforated specimens were entirely silky in appearance, with the exception of one of the ¾ inch, and two of the 1 inch plates, in which 5 per cent. of each of the fractures was granular, the remainder being silky. The extent to which the appearance of the fractures was affected by the treatment the specimens had undergone is shown by the following summary of results taken from Tables 2, 3, 4, and 5 :—

Specimens.	Appearance of Fractures of Perforated Plates.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
Drilled -	100 % silky	100 % silky -	95 % silky - 5 % granular -	20 % silky. 80 % granular.
„ -	100 % „	100 % „ -	92 % silky - 8 % granular -	93 % silky. 7 % granular.
Punched -	100 % „	95 % „ - 5 % granular -	30 % silky - 70 % granular -	100 % „
„ -	100 % „	100 % silky -	45 % silky - 55 % granular	3 % silky. 97 % granular.
Punched and annealed -	100 % „	100 % „ -	100 % silky -	83 % silky. 17 % granular.
Punched and annealed -	100 % „	100 % „ -	100 % „ -	100 % silky.

The appearance of fracture of the ¼ and ½ inch specimens is thus almost wholly silky. In the ¾-inch punched specimens there is considerable granular appearanee, and table 4 shows by the reduced elongation of the holes that the specimens broke more suddenly than the drilled or annealed specimens of which the fractures were almost wholly silky. Of the two 1-inch drilled specimens one broke with a fracture 80 per cent. granular, and the other almost wholly silky ; the former is seen by the reduced elongation of the holes to have broken more suddenly than the latter. The 1-inch punched plates broke with an almost wholly granular fracture, and by the very small elongation of the holes are shown to have broken suddenly. In the 1-inch punched specimens off the same plates, and which were annealed after punching the elongation at fracture was considerably greater than in the punched specimens, and the mean granular portion of the fracture was reduced from 98½ to 8½ per cent. These results would appear to show that the fact of mild steel displaying a granular appearance does not necessarily imply that the material is brittle, but that it depends upon whether the specimen breaks suddenly or with considerable elongation or contraction of area at fracture. They also show that, as a rule, if the cause such as the effect of punching, &c., which led to sudden failure, is removed by annealing or otherwise, the fracture changes from granular to silky.

The intimate connection between the nature of the fracture silky or granular, and the gradual or sudden character of the break, is perhaps better recognized after inspecting the different specimens. It is seen that when by the absence of contraction of area or extension the specimen broke suddenly, the fracture is square and granular in appearence. When, however, the break has occurred with considerable contraction of area or extension, the fracture in place of being square is drawn out, and angular either from one side or the centre, the corresponding fracture in the latter case being cup-shaped.

In the specimens experimented with already referred to, the holes in the plates and riveted joints were either drilled or punched. It is not, however, unfrequently the case that rivet holes are punched small, and bored to the size required, with the object of removing the zone of metal affected by punching.

It had long been considered desirable to ascertain with some degree of certainty to what extent, if any, the subsequent boring of the holes removed the injurious effects of punching, when Mr. Halket, the manager of the Glengall Ironworks, Millwall, kindly offered to prepare the necessary specimens for testing free of cost, the Steel Company of Scotland also kindly supplying the steel plates.

In order that the strength of plates with holes punched small, and bored to size, might the more justly be compared with those treated in the manner already referred to, it was considered desirable that some specimens so treated should be cut from the same plates. This plan obviated the possibility of any uncertainty when comparing the results from there being a slight difference between the plates.

Eight specimens, ¼, ½, ¾, and 1-inch thick, were prepared, or 32 in all. One of each thickness was unperforated, one was drilled, two were punched, two were punched small and bored to size, and two were punched and the plates afterwards annealed. It was intended to have prepared two unperforated and two drilled specimens, but the plates ordered were scarcely large enough to allow of it. In order to enable a comparison to be readily made between the strength of the specimens treated in the different ways referred to, the sectional areas of the plain and perforated specimens were made as nearly as possible the same, the small diameter of the punched holes being made the same size as the drilled holes. The specimens were not sheared, but were all planed out of the solid plate, so as to avoid any disturbance of the texture of the material. The holes were perforated before the specimens were shaped, the punches and dies being in good average condition. The plates which were annealed were heated to a cherry red in a plate furnace, and covered with ashes until cold. In punching the holes, the bolsters or dies used were larger than the punches by about one-fifth of the diameter, this proportion being adopted as affording a moderate degree of clearance to the punch.

In the case of some experiments on mild steel to ascertain the effects of using bolsters of different sizes with the same punch, the results of which have been published elsewhere, it has been stated that a large benefit is derived from the use of dies giving considerable clearance to the punch. When, however, the results are examined it is observed that the comparison is made between the ultimate stresses per square inch of the section of metal obtained by deducting the taper punched holes from the total section, instead of that found by deducting parallel holes the size of the small end of the hole. It is of course possible that the results mentioned may be obtained in some cases when the calculation is made in the proper way, but it should not be forgotten that a plate punched with holes having a considerable amount of taper, although less injured by punching, may as a whole be weaker than a plate punched with nearly parallel holes, owing to the large amount of metal punched out; such a result is indeed often observed.

In order properly to compare the results of using dies of different sizes with the same punch, the stresses should be calculated with reference to the gross area of the plate at the holes, or else with reference to, what is proportional to it, the net area between the holes calculated upon the assumption of the holes being parallel the size of the small end. Similarly, if plates with punched holes be compared with others having drilled holes, the stresses of both sets of plates should be calculated in the same way. The necessity of this is seen if the plates are pulled apart, as the effect of the reduced section on the punched plates then becomes apparent.

In the case of the holes punched small, and bored to size, the following proportions were adopted as fair, and such as would be adopted in general practice, the boring being performed by a parallel twist drill.

Thickness of Plate.	Holes Punched. Diameter.	Bored to. Diameter.
inch.	inch.	inch.
$\frac{1}{4}$	$\frac{13}{64}$	$\frac{1}{4}$
$\frac{1}{2}$	$\frac{13}{32}$	$\frac{1}{2}$
$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$
1	$\frac{13}{16}$	1

The results of the experiments are given on tables 20, 21, 22, and 23.

The following summary contains the mean ultimate stresses per square inch of net area:—

Specimens.	Ultimate Stress per Square Inch of Net Section.			
	$\frac{1}{4}$-inch	$\frac{1}{2}$-inch.	$\frac{3}{4}$-inch.	1-inch.
	tons.	tons.	tons.	tons.
Punched -	28·33	25·33	22·94	21·26
Punched and annealed -	31·6	29·39	29·31	29·12
Punched small and bored to size -	31·23	30·86	28·81	29·15
Drilled - -	31·46	31·37	30·23	28·43
Unperforated -	30·17	27·69	27·84	28·17

These figures enable a comparison to be made very readily between the results of the different treatment the specimens have undergone. The stresses if expressed in terms of the per-centage of strength of the solid plate are as follows:—

Specimens.	Ultimate Stress per Square Inch of Net Section compared with Solid Plate (=100).			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Punched - -	93·8	91·4	82·3	75·4
Punched and annealed - -	104·7	106·1	105·2	103·3
Punched small and bored to size	103·5	111·4	103·4	103·4
Drilled - -	104·2	113·2	108·5	100·9

The losses and gains of the perforated plates as compared with the unperforated are given below :—

Specimens.	Difference between the Ultimate Stresses per Square Inch of Net Section of Perforated and Unperforated Plates.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Punched - -	loss 6·2	loss 8·6	loss 17·7	loss 24·6
Punched and annealed - -	gain 4·7	gain 6·1	gain 5·2	gain 3·3
Punched small and bored to size	„ 3·5	„ 11·4	„ 3·4	„ 3·4
Drilled - -	„ 4·2	„ 13·2	„ 8·5	„ 0·9

The ultimate stresses of all the perforated specimens except the punched are like those previously tested greater than the stresses of the unperforated plates; this is no doubt due to the causes already alluded to as having caused a similar result.

Comparing the punched plates with those in which the holes are punched small and bored to size, we find that whilst with the former there is with the ¼, ½, ¾, and one inch specimens a loss compared with the solid plate of 6·2, 8·6, 17·7, and 24·6 per cent. there is in the latter a gain of 3·5, 11·4, 3·4, and 3·4 per cent. respectively, making a total gain, with the specimens in which the holes were bored after punching, over those in which they were punched, of 9·7, 20·0, 21·1, and 28 per cent. The effect of boring after punching, like that of annealing, is to remove nearly all the injurious effects of the punch as indicated by the tensile stress. The mean excess of the drilled specimens is greater than either of the others. The 1-inch drilled specimens do not give so high a result as those previously obtained, and for that reason it is to be regretted that only one drilled specimen was tested in this series.

That the ductility of the material is affected by the treatment the material undergoes is clearly shown by the elongation of the holes at the ultimate stress:—

Specimens.	Elongation of Holes at Ultimate Stress.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Punched - -	9·5	12·0	10·6	3·0
Punched and annealed - -	36·5	43·0	35·3	26·0
Punched small and bored to size	22·0	28·5	22·6	25·0
Drilled - -	32·0	44·0	32·0	44·0

We thus see that whilst in the punched specimens of all thicknesses there is a mean elongation of the holes of 8·7 per cent., the same in the punched and annealed, punched small and bored to size, and the drilled specimens are respectively 35·2, 24·5, and 38 per-cent. The mean elongation of the holes in the punched and annealed and drilled specimens are thus nearly equal, and exceed by four times that of the punched.

The specimens in which the holes were punched small and bored to size gave scarcely such good results as the drilled, but as the elongation of the holes is about three times that with the punched plates, the advantage of boring the holes after punching is as regards ductility clearly proved.

The advantage of drilling compared with punching, as regards the ductility of the specimens, is most clearly shown in those 1 inch thick, the elongation of the holes in the drilled specimens being 44 per cent., whilst it is only 3·0 per cent. in the punched. The result is perhaps such as might be expected considering that the ultimate stress per square inch of the punched plate is 24 per cent. less than that of the solid plate the per-centage of the elongation of the holes bored after punching is nearly the same in all thicknesses, but being considerably less than in the drilled, and punched and annealed specimens, would appear to show that the ductility is impaired, and that the quantity of metal bored out is less than requisite to remove the whole injury arising from punching.

The fractured area of the specimens like the elongation of the holes is considerably affected by the treatment the material undergoes. This is shown by the summary attached:—

Specimens.	Mean Contraction of Area at Fracture.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Punched - -	24·1	19·1	13·0	5·4
Punched and annealed - -	41·3	37·4	30·7	24·7
Punched small and bored to size -	24·0	28·9	19·4	15·9
Drilled - -	36·6	32·7	32·1	33·2
Unperforated -	53·3	50·0	39·4	38·8

The mean contraction of area of the punched specimens of all thicknesses is 15·4 per-cent., and of those punched and annealed, punched and bored, and drilled, 33·5, 22·0, 33·6 per cent. respectively, the lowest value, 15·4, indicating considerable injury from punching.

In the specimens in which the holes were bored after punching, the contraction of area is much greater than occurred with the punched, and indicates a beneficial effect having resulted from the subsequent boring. It is, however, like the elongation of the holes less than with the punched and annealed, and drilled specimens, and is an additional argument proving that the quantity of metal bored out of the punched holes is not quite sufficient to remove the whole injury arising from punching. In the punched specimens the contraction of area becomes less as the thickness increases, and varies in about the inverse ratio of the injury arising from punching. This is most clearly shown by the ¼ and 1 inch specimens in which the loss of strength by punching is respectively 6·2 and 24·6 per cent., whilst the contraction of area is 24·1 and 5·4.

We have already when dealing with previous tables considered the extension of the unperforated plates at the ultimate stress as well as at 50,000lbs. and 60,000 lbs. per square inch. In tables 20, 21, 22, and 23 the means are afforded of comparing the extensions of the perforated plates at the same stresses.

The particulars given are of great value when considering the extension that is likely to occur in the circular shell of a steam boiler upon the application of definite stresses. It is not uncommonly suggested that a steam boiler may be allowed to work at a particular pressure if the application of the same, or a somewhat higher stress, is borne without distortion or perceptible lengthening of the boiler plates circumferentially. The great ductility of this steel has been suggested as affording a means of knowing when undue strain is being applied.

The particulars in columns 15 to 17 in the tables referred to, give convincing proof of what has long been known, but possibly overlooked by those making the above suggestion, viz.:—that the effect of perforating a plate in one or more lines across the direction of stress is to cause lines of weakness at those parts to which also the extension is almost wholly confined. Consequently, owing to the form of the specimen where weakened, and the shortness of the length over which extension occurs as compared with 10 inches, the per-centage of extension upon that length is very much less than in the unperforated specimen.

Specimens.	Mean Ultimate Extension set in 10 inches of Perforated Specimens.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Punched - -	1·7	2·9	2·4	0·75
Punched and annealed - -	5·8	8·0	8·5	8·0
Punched and bored	4·2	6·6	6·7	7·5
Drilled - -	5·8	7·8	9·2	12·0
Unperforated -	22·9	30·3	80·6	29·0

The mean ultimate extension in 10 inches of all the perforated specimens, ¼, ½, ¾, and 1 inch thick, are respectively 4·3, 6·3, 6·7, 7·0 per cent., the ultimate extensions of the unperforated plates being respectively 22·9, 30·3, 30·6, and 29·0 per cent. As the diameter of the holes is not the same in all the thicknesses of plates, and consequently the effective length for stretching differs, it is not right to compare the extension of a perforated plate of one thickness with that of another. Comparing, however, the ultimate extension of the different specimens of the same thickness, we find that in the punched it is very much less than either of the others, thus showing the injurious effects of punching. Taking the others in the order of amount of extension we have generally:—

(1.) Drilled.
(2.) Punched and annealed.
(3.) Punched and bored.

The smaller extension of the specimens in which the holes were bored after being punched, compared with the annealed and drilled specimens, appears to prove that the quantity of metal bored out after punching was scarcely sufficient to remove the whole effect of punching.

Comparing the results obtained with the specimens in which the holes were punched, with those in which they were punched small and bored to the size required, it is clear that a decided advantage is obtained in the latter over the former as regards tensile stress and ductility. Notwithstanding this fact, however, the system is not to be recommended unless the quantities bored out are considerably in excess of those removed in the fore-going experiments. The reason of this is obvious. However carefully holes are punched, a certain amount of unfairness between those in the different plates when placed together for riveting is sure to occur. The particulars given show that the amounts bored out of the plates experimented with, were scarcely sufficient to remove the whole injury arising from the effects of punching. Unless therefore in boiler work a much larger quantity is bored out, the unequal removal of metal at the sides of the holes caused by their unfairness, is liable to leave unremoved a quantity of metal affected by punching, and therefore especially in thick plates liable to cause a considerable reduction in strength. The careful annealing of all steel plates after punching, or better still the drilling of the holes is therefore much to be preferred to the boring of rivet holes after punching.

Summarising the extension in 10 inches at stresses of 50,000 lbs. and 60,000 lbs. per square inch of net section, we have as follows:—

Specimens.	Mean Extension Set in 10 inches.							
	¼-inch.		½-inch.		¾-inch.		1-inch.	
	At 50,000 lbs. per Square Inch of Net Section.	At 60,000 lbs. per Square Inch of Net Section.	At 50,000 lbs. per Square Inch of Net Section.	At 60,000 lbs. per Square Inch of Net Section.	At 50,000 lbs. per Square Inch of Net Section.	At 60,000 lbs. per Square Inch of Net Section.	At 50,000 lbs. per Square Inch of Net Section.	At 60,000 lbs. per Square Inch of Net Section.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Punched -	Nil.	·25	·35	Broken	·8	Broken	Broken	Broken
Punched and annealed -	·05	·45	·8	2·45	1·55	3·85	1·6	4·1
Punched and bored -	·05	·65	·45	2.1	1·05	3·5	1·8	5.1
Drilled - -	·2	·5	·9	2·9	1·5	3·9	2·3	5·1
Unperforated	3·5	12·0	4·8	13·5	4·6	12·4	4·7	12·8

It has been shown that the ultimate extension of the punched specimens is much less than that of the punched and annealed, punched and bored, and drilled; this is also the case at 50,000 and 60,000 lbs. per square inch of net area. All the one inch and one of the three-quarter inch punched specimens broke at a lower stress than 50,000 lbs. per square inch. At this stress the extension sets in 10 inches of the punched specimens, ¼, ½, and ¾ inch thick are 0, 0·35, and 0·8 per cent. against 0·1, 0·71, 1·36 per cent., which are the mean values for the above thicknesses of the punched and annealed, punched and bored, and drilled. The smaller extension with the punched specimens is most marked with those ¾ inch thick.

The above results are most important as they show that the effect of punching is to reduce the ductility of the plate in the same way as if a hardening effect had taken place.

The following summary shows the comparison between the mean stresses of all the perforated plates of the different thicknesses at 50,000 lbs. and 60,000 lbs. per square inch, and at the ultimate stress:—

Thickness of Plate.	Mean Extension Sets in 10 inches of the Perforated Specimens.		
	At 50,000 lbs. per Square Inch of Net Area.	At 60,000 lbs. per Square Inch of Net Area.	Ultimate.
	per cent.	per cent.	per cent.
$\frac{1}{4}$ inch - -	·07	·46	4·3
$\frac{1}{2}$,, - -	·62	1·86	6·3
$\frac{3}{4}$,, - -	1·22	2·8	6·7
1 ,, - -	1·42	3·57	7·0

Attention has previously been directed to the smaller extension set of the unperforated plates at stresses of 50,000 lbs. and 60,000 lbs. per square inch, as compared with the ultimate extension set, in order to show that the ultimate extension of the material, although large, consists to a great extent of elongation, due to contraction of area at fracture. The above summary shows that a similar result occurs with the perforated plates. The mean extension set in 10 inches at 50,000 lbs. and 60,000 lbs. per square inch, and at the ultimate stress, being respectively 0·83, 2·17 and 6·1 per cent., whilst the same values for the unperforated plates in the series are respectively 4·4, 12·6, and 28·2 per cent.

The effect of perforating the steel plates is thus seen to greatly affect the elongation, the effects being most marked in the punched plates, and least in the drilled. The extension of a mild steel unperforated plate at a safe working stress is very small. It is also reduced more or less by the presence of rivet holes according as they are drilled or punched, and being localised at the holes is difficult to measure with any degree of accuracy; no dependence can, therefore, be placed upon it as a means of detecting when undue strains are applied in the manner suggested.

In the outer strakes of plating of the hulls of vessels the rivet holes are punched, and afterwards countersunk, the countersinking according to the best practice extending right through the plate, or nearly so. The metal affected by punching is thus drilled out with the exception of a small portion on one side of the plate.

The injurious effects of punching, especially upon thick steel plates, whilst very great, have been shown to be largely removed by the subsequent boring out of a narrow zone of metal, the whole thickness of the plate. It was, however, considered desirable to ascertain by actual experiment to what extent, if any, the strength and ductility of the steel plate might be affected by the non-removal from one side of the plate of a narrow ring of metal which had been subjected to the effects of punching. The Steel Company of Scotland were requested to supply three steel plates, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch thick of the quality usually supplied by them for the construction of the hulls of vessels, which they readily agreed to do.

Six specimens were cut lengthway out of each plate, two were unperforated, two were punched and afterwards countersunk, and two were drilled and countersunk. The countersinking extended right through the plate, and was of course done from the large side of the hole. The holes in the drilled specimens were made by a parallel twist drill. In the punched specimens the proportion of the dies to the punches with which they were respectively used, is as nearly as possible the same as that adopted in the perforated plates already dealt with.

Attention has already been directed to the effect which the perforation of holes in a plate has upon the ultimate tensile stress, &c. If the tensile stress of the punched and countersunk plates were compared only with those of unperforated plates, it is evident that a certain amount of uncertainty must exist respecting the effects of the punching, owing to the form of the specimens at the point of fracture affecting the ultimate stress. For this reason the specimens which were drilled and countersunk were prepared and tested in order that the ultimate tensile stress, &c. of the punched and countersunk specimens might be compared with others similar in form, and which had not been injured when perforated.

The results of the tests are given in Table 24.

The ultimate tensile stresses of the unperforated plates, ½, ¾, and 1 inch thick, are respectively 25·76, 26·65, and 27·28 tons per square inch, the contraction of area at fracture 47·69, 41·96, 48·07 per cent. respectively, and the ultimate extension 30·5, 28·0, and 30·3 per cent. respectively. The ultimate stresses are thus considerably lower than of the steel boiler plates previously tested, but possess about the same degree of ductility. The ductility is, it may be remarked, greater than that usually found in the steel plates generally supplied for the hulls of vessels.

Summarising the ultimate stresses per square inch of net section, we have as follows:—

Specimens.	Ultimate Stress per Square Inch of Net Section.		
	½ inch.	¾-inch.	1-inch.
	tons.	tons.	tons.
Punched and countersunk -	27·67	28·82	29·53
Drilled and countersunk -	27·44	29·20	29·22
Unperforated - - -	25·76	26·65	27·28

It will be seen that, taking the mean of the punched and countersunk, and the drilled and countersunk specimens ½, ¾, and 1 inch thick, that the mean ultimate stresses are practically equal, being 28·67 tons and 28·62 tons per square inch, showing that as regards ultimate stress the countersinking of the punched holes has removed the injurious effects of punching.

The ultimate stress of the perforated specimens is greater than that of the unperforated, a result due to the holes affecting the facility for contraction of area at the point of fracture.

The calculation of the ultimate stresses per square inch of net section has been made by deducting the mean diameter of the holes. If, as in previous cases, the small diameter of the holes be deducted, we have for the punched and countersunk, and drilled and countersunk specimens ½, ¾, and 1 inch thick, the ultimate stresses 26·87 tons and 26·76 tons per square inch respectively. The mean ultimate stress of the unperforated specimens is 26·56 tons per square inch, so that even with the loss of the metal removed by the countersinking the ultimate stress of the perforated specimens slightly exceeds that of the unperforated.

Notwithstanding the above, it does not appear upon consideration of the following summary that all the effects of punching are removed.

Specimens.	Contraction of Area at Fracture.		
	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.
Punched and countersunk -	25·66	18·88	16·26
Drilled and countersunk -	29·63	22·33	17·86
Unperforated - - -	47·69	41·96	48·07

The contraction of area at fracture of the punched and countersunk specimens is less for all the thicknesses than for those drilled and countersunk, and would appear to show that the ductility of the former is less than the latter, a result possibly caused by the hardening effect locally on the plate of the operation of punching.

The following summary of the ultimate extension sets indicates the same effect, the extension set of the punched and countersunk specimens being in each case less than the drilled and countersunk.

Specimens.	Ultimate Extension Set in 10 inches.		
	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.
Punched and countersunk -	8·75	7·75	7·25
Drilled and countersunk -	9·4	10·0	10·0
Unperforated - - -	30·5	28·0	30·3

The smaller contraction of area of the perforated specimens as compared with that of the unperforated, is due to the effect of the form of the specimen at the holes which has been previously referred to. The smaller extension set in 10 inches of the perforated specimens as compared with that of the unperforated is caused by the extension being confined to the metal at the lines of weakness across the plate at the holes.

RESPECTING the RESULTS of TESTING by PULLING STRESS some RIVETED JOINTS.

Tables 6, 7, 14, and 15, give the results of testing some triple riveted lap joints made of steel plates ¼, ½, ¾, and 1 inch thick. There were four joints of each thickness, the rivet holes in two of each being drilled, and in two of each punched; the plates of one of the punched joints of each thickness were annealed after punching, by being heated to a cherry red, and covered with ashes until cold. The rivets in the drilled joints were pitched so that one joint of each thickness should give way by tearing the plate through a line of rivet holes, and the other by shearing the rivets. The holes in all the joints of one thickness were made to take the same size rivets, the small diameter of the punched holes being the same size as the drilled holes, the sides of the plates from which the holes were punched being placed together. The joints were steam machine riveted with steel rivets supplied by the Steel Company of Scotland. The plates were drilled by Mr. Kirkaldy, but the punching, annealing, and riveting, were performed at the works of Messrs. J. and G. Rennie.

As regards the riveting Messrs. Rennie state that no special instructions were given to their workmen regarding the rivets, and that no difficulty was experienced with them. There appears from the results of the tests to be no doubt that if steel rivets are judiciously selected for the special qualities required, and if care be taken in heating them, that no trouble need be anticipated with them. Tables 8 and 16 give the results of testing them for tensile stress, &c.; their shearing stress was ascertained by the experiments on those riveted joints which failed by the shearing of the rivets. Turning to Mr. Kirkaldy's report we have as follows:—

Specimen.	Ultimate Stress per Square Inch of Gross Area at Joint.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	tons.	tons.	tons.	tons.
Drilled - -	26·3	22·3	20·6	19·1
Punched - -	22·8	19·6	18·6	8·8
Punched and annealed - -	23·7	20·9	20·6	19·0

The above stresses are computed with reference to the total sectional area of the plate at the joint, including therein that removed by the rivet holes. The results obtained with the joints of different thicknesses cannot therefore be compared, unless the per-centage of metal removed by perforation be the same in all cases. The summary, however, enables a comparison to be made between the values of the drilled, punched, and punched and annealed joints of each thickness respectively, and gives the ultimate stress per inch run of joints. The greater stresses borne by the drilled joints as compared with the punched is very marked, especially in the case of those 1 inch thick.

The results of testing the joints of different thicknesses can be compared if the stresses are calculated in terms per square inch of net section between the rivet holes as follows:—

Specimen.	Ultimate Stress per Square Inch of Net Section between the Rivet Holes.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	tons.	tons.	tons.	tons.
Drilled - -	35·95	34·16	30·46	29·44
Punched - -	31·75	30·2	27·79	13·6
Punched and annealed - -	32·91	32·21	30·62	29·5

As the drilled joints were made previous to those punched, and punched and annealed, and consequently from different plates, the results can more fairly be compared if the stresses are expressed in terms of the per-centage of strength of the unperforated plates from which they were respectively cut, thus:—

Specimen.	Stress per Square Inch of Net Section compared with Solid Plate (=100).			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Drilled - -	113·8	117·2	106·5	105·9
Punched - -	106·0	107·9	96·6	47·8
Punched and annealed - -	109·9	114·8	106·5	103·8

These per-centages express the relation between the stresses borne by the net section of plate between the rivet holes, and by unperforated plates of equal section. The loss of strength arising from the removal of plate by punching or drilling is not included.

The losses and gains of the different joints as compared with the unperforated plates are as follows:—

Specimen.	Difference between the Ultimate Stresses of the Net Section of Plate in the Riveted Joints, and the Solid Plate.			
	¼-inch.	½-inch.	¾-inch.	1-inch.
	per cent.	per cent.	per cent.	per cent.
Drilled - -	gain 13·8	gain 17·2	gain 6·5	gain 5·9
Punched - -	„ 6·0	„ 7·9	loss 3·4	loss 52·2
Punched and annealed - -	„ 9·9	„ 14·8	gain 6·5	gain 3·8

The ultimate stress per square inch of the net section of the drilled joints between the holes is thus greater than the ultimate stress per square inch of the solid plate, the excesses for the ¼, ½, ¾, and 1 inch joints being 13·8, 17·2, 6·5, and 5·9 per cent. The punched and annealed joints also show an increase although generally to a rather less extent. The punched joints, ¼ and ½ inch thick, show an excess over the unperforated plates of 6·0, and 7·9 per cent., but in the ¾ and 1 inch punched joints the losses are 3·4, and 52·2 per cent. The above losses do not include those due to the material removed by the rivet holes which must accordingly be added in order to obtain the total loss of strength on a definite length of plate. Had the material between the rivet holes after punching been equal in strength to the solid plate the 1-inch joint should have sustained a load of 28·4 tons per square inch, whereas it only sustained 13·6 tons per square inch. Were a steam boiler constructed with similar longitudinal joints the working pressure should thus be reduced as 28·4 to 13·6, or more than one-half, in order that the boiler shell might be equally strong with another of which the material was not thus injured. Few facts are more convincing as to the necessity for avoiding punching thick plates, or at any rate of carefully annealing them afterwards.

It will be observed that the amount of injury sustained by the 1-inch joint owing to the effects of punching is much greater than occurred with the straight punched plates dealt with in a previous section. The question thus arises, to what is this difference due? The following remarks are offered in order to throw light upon the subject. When two plates are connected by a riveted lap joint the plates when subjected to severe pulling stress no longer remain in the position shown in fig. 1, but take that in fig. 2.

Fig. 1.

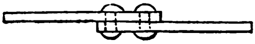
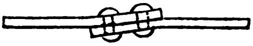


Fig. 2.



It has been conclusively proved that with ordinary iron plates, especially thick plates which fracture when bent to a small angle, that the bending which occurs as the form of the joint changes under a pulling stress from fig. 1 to fig. 2 exerts a very injurious effect upon the ultimate stress. This was commented upon by Sir William Fairbairn many years ago. It will probably be remarked that in the case of the lap riveted steel joints in this series of experiments, in which the plates were (1) drilled, and (2) punched, and afterwards annealed, that the injurious effects, when under a pulling stress, of the bending arising from lap jointing are not shown, but the explanation of this fact appears to be that, the steel being a ductile material, the bending action which occurs under a gradually applied pulling stress does not materially affect the ultimate stress unless the treatment the metal has received, has been such as to reduced the angle to which it can be bent without injury.

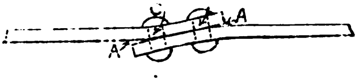
The above remarks are offered as the probable cause of the effects observed, but the extent to which the ultimate stress of double and treble riveted lap joints made of steel plate are affected by the bending action referred to above, is a subject of very great importance which demands further experimental inquiry, which if carried out should embrace steel made by different manufacturers.

Apart from the additional loss of strength in the punched joint apparently caused by the bending action, arising from the form of the joint, the loss of strength in the 1-inch straight-punched plates is sufficiently large to cause the greatest suspicion concerning all thick steel plates in which the holes are punched, unless the plates are subsequently carefully annealed. It should be remarked that since these experiments were made, others have been carried out with the mild steel of other manufacturers, and similar results proving the injurious effects of punching have been obtained.

After the conclusion of the experiments it was found that, in the construction of the riveted joints, the pieces of plate of which they were made were riveted together so that whilst the strain on one was in the lengthway direction of the original plate, the strain on the other was crossway. With the exception of the $\frac{1}{4}$-inch drilled joint it was found that in each of the joints in which the plate failed it was the plate strained in the crossway direction which fractured. As the perforated plates were cut lengthway of the original plates, we cannot therefore fairly compare the stresses of the riveted joints with the stresses borne by the perforated plates, which might otherwise profitably have been done.

It has been usual in some quarters when considering the ultimate stresses borne by riveted joints to attribute considerable importance to the friction between the plates caused by the force with which they are held together by the rivets. Whatever value may justly be attached to this at the ordinary working stress, an inspection of the riveted joint when being tested to destruction effectually dispels all idea of the ultimate stress being in the slightest degree affected by it, owing to the extent to which the joint gapes, as shown in the annexed sketch, Fig. 3.

Fig. 3.



It is interesting to note that the higher the stress sustained, as in the case of riveted joints with drilled holes, the greater amount of opening is observed at A.

In the case of some 1 inch treble riveted lap joints which have been tested for the Board of Trade, the opening has in some cases been as much as $\frac{5}{16}$ inch. It is scarcely necessary to insist upon the fact that under such conditions the ultimate stress of the material either at C or D, where fracture occurs, cannot be increased by any amount of friction which existed at the time of construction.

It may not be amiss to remark that even in the case of riveted joints fitted with double butt straps the bending of the rivets causes the butt straps to open, and apparently destroys all friction between the plates and butt straps.

The actual strength of the riveted joints, in terms of the per-centage of strength of the solid plates, can be deduced from the results of experiments made by Mr. Kirkaldy. It may be useful to compare them with the per-centage obtained by calculation by the usual formula.

$$\left.\begin{array}{l}\text{Per-centage of strength of plate at}\\ \text{joint as compared with solid plate}\end{array}\right\} = \frac{P-D}{P} \times 100.$$

when $P =$ Pitch of rivets in inches, and $D =$ Diameter of rivets in inches.

Comparison between the Calculated and Actual Strength of Joints.

—	¼-inch.			½-inch.			¾-inch.			1-inch.		
	Drilled.	Punched.	Punched and Annealed.	Drilled.	Punched.	Punched and Annealed.	Drilled.	Punched.	Punched and Annealed.	Drilled.	Punched.	Punched and Annealed.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Calculated per-centage of strength of plate at joint as compared with solid plate or $\frac{P - D}{P} \times 100$	73·3	72·1	72·1	65·5	64·7	64·7	67·6	66·9	66·9	64·7	64·4	64·4
Actual ratio of strength of joint to solid plate	83·4	76·3	79·1	76·8	69·9	74·4	72·1	64·7	71·3	68·5	30·8	66·8
Gains or losses of actual strength compared with calculated strength of joints	gain 10·1	gain 4·2	gain 7·0	gain 11·3	gain 5·2	gain 9·7	gain 4·5	loss 2·2	gain 4·4	gain 3·8	loss 33·6	gain 2·4

Taking the difference between the values of the two first lines in the table we have the difference between the calculated and actual strength of the joint in terms of the per-centage of strength of the solid plate. It will be observed that with the ¼ and ½ inch joints the actual strength of the joint is in excess of the calculated, whether the holes be drilled, punched, or punched and annealed, and that the excesses are greatest in the drilled and least in the punched. The actual strength of the ¾ inch drilled, and punched and annealed joints, is about 4 per cent. in excess of the calculated strength; but in the punched joint the actual strength is 2·2 per cent. less than the calculated. Whilst the actual and calculated strength of the 1-inch drilled and punched and annealed joints are very close, the actual strength of the 1-inch punched joint is 33·6 per cent. below the calculated strength; the serious nature of this fact has been already referred to. The fact of the actual ultimate stress of the joints being in excess of the calculated, based upon the ultimate stress of the solid plate, is to be imputed to the same causes which led to a similar result with the perforated plates, viz., the form of the plate at the holes where fracture takes place. It will be remembered that in the perforated plates the injury from punching is much less in the ¼ and ½ inch than in the ¾ and 1 inch plates; accordingly we find that in the riveted joints ¼ and ½ inch thick, the increase in the stress due to the form of the plate at the rivet holes is sufficient to outweigh the injury from punching. In the ¾ and 1 inch plates, on the contrary, the injury from punching is considerable, and in the latter exceeds to a very great extent the advantage arising from the form. In the joints of each thickness which were punched and afterwards annealed, the excess of the actual stress over the calculated was in each case less than with the drilled. This may have arisen (1), from the annealing of the perforated plates being insufficient to remove the whole injury arising from punching; (2), as is sometimes the case, from the ultimate stress of the annealed plates being reduced by the process of annealing; or (3), from a greater amount of metal being removed by the taper punched holes as compared with the parallel drilled holes, the loss of strength arising from which, annealing cannot be expected to recover.

In addition to the riveted joints which broke through the plate at the rivet holes, and which we have been considering, four drilled joints ¼, ½, ¾, and 1 inch thick respectively, were however, arranged so that they should fail by shearing the rivets, in order to ascertain their shearing stress. The particulars are given on tables 6 and 7. Owing to each joint being of considerable width, and that in each case a number of rivets sheared simultaneously, the conditions of the experiment approximate very closely to those present in a marine boiler under pressure. It is only by the shearing of at least several rivets at one time in a well-proportioned joint, that the correct shearing stress referred to above can be obtained, experience having shown that the shearing of a single rivet often gives fallacious results. In the following table are given the ultimate tensile stress per square inch of net section of the drilled joints which gave way through the plate, and the ultimate shearing stress per square inch of the rivets in the other drilled joints of the same thickness:—

Thickness of Joint.	Ultimate Tensile Stress per Square Inch of Net Section of Plate at Joint with Drilled Holes.	Ultimate Shearing Stress of Rivets per Square Inch.	Tensile Stress of the Rivets per Square Inch.	Diameter of Rivets.
	tons.	tons.	tons.	inch.
$\frac{1}{4}$ inch -	35·95	25·1	31·2	$\frac{7}{16}$
$\frac{1}{2}$,, -	34·16	25·5	30·6	$\frac{5}{8}$
$\frac{3}{4}$,, -	30·46	23·9	28·6	$\frac{15}{16}$
1 ,, -	29·44	24·1	30·1	$1\frac{1}{16}$

The shearing stress of the rivets being so much less than the tensile stress of the plate, renders it necessary in correctly proportioning a riveted joint to make the area of the rivets under shear considerably in excess of the sectional area of the plate. In fact in the $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch joints the rivet area should be respectively 1·43, 1·33, 1·27, and 1·22 times the net area of the plate between the rivets, in order that the strength of plates and rivets may be equal. These proportions are based upon the results obtained with the drilled joints.

Table 19, giving the results of some experiments carried out with rivets made of steel of various qualities, shows that the ultimate tensile stress varies considerably. The mean ultimate stress of the rivets used in the riveted joints which were tested, differs very slightly from that of the rivets with the highest stress given in the table. No experiments have been made to ascertain the shearing stress of the rivets with the lower tensile stress, but if it should prove to be as much less as with the rivets used in the joints, care must be taken to increase the rivet area proportionally.

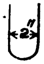
The proper proportioning of the rivets in joints is a matter of very great importance, and in the construction of marine steam-boilers great attention has been paid to it for some years. In the butt joints of even iron vessels, however, much has yet to be done to render the proportions satisfactory, the rivet section being frequently much less in strength than the net section of the plate between them. The fact of the tensile stress of the steel plate exceeding the shearing stress of the steel rivets to a much greater degree than the tensile stress of the iron plate exceeds the shearing stress of the iron rivets, renders it especially necessary with steel to make a greater allowance for the lower proportional shearing stress of the rivets.

Although in the above remarks the rivets have been spoken of as failing by "shearing," this, although the usual term, does not quite correctly represent the action that takes place. When a lap riveted joint is subject to a severe pulling stress, the joint is distorted as shown in Fig. 3, the rivets instead of being at right angles to the line of stress occupying a more oblique position. As the alteration of form takes place the rivets lengthen, and finally give way under a force which although principally shearing is partly tensile.

RESPECTING RESULTS of EXPERIMENTS upon STEEL PLATES to ascertain the effects of BENDING STRESS.

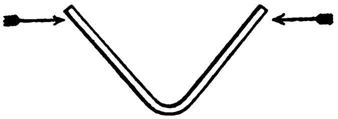
Tables 9 and 17 give the results of experiments made by Mr. Kirkaldy to ascertain the resistance to bending of the series of steel plates previously referred to in this report. They were tested, *firstly*, in the condition received, and *secondly*, after having been heated to a cherry red and cooled suddenly in water at a temperature of about 80° Fahrenheit. These tests were made by Mr. Kirkaldy with the very great care which has characterised all the experiments which he has made for the Board of Trade.

It will be observed that at the foot of table 17 he remarks with reference to the plates heated to a cherry red and cooled in water, as follows:—"As plates are *never* subjected in actual " practice to the above treatment I have always verbally objected " to making such tests, and I now put my dissent on record." It is, of course, true that, if ordinary care be observed in the manipulation of steel in the ship-yard, or boiler-yard, it would never be heated to a cherry red and cooled in water, but the value of the test consists in its affording a ready means of detecting a slightly brittle plate, which, from having been well annealed, might have passed the cold bending test satisfactorily. The advantage of this safeguard is fully recognised by engineers and shipbuilders generally, as well as by the Steel Company of Scotland. At the works of the latter at Newton a man is stationed by the shearing machine whose sole duty it is to take a portion of a shearing from each plate, heat it to a cherry red, cool it suddenly in water, and then bend it, the plate being rejected if the test is not satisfactory. The experience of the Company has evidently shown them that if the result of the test is not satisfactory, the plate, although it might stand the bending test without the heating and cooling as above, cannot be depended upon to have the necessary ductility to enable it to bear the treatment it may receive whilst being worked into a ship or boiler.

The plates experimented upon were of the nominal thickness of $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch. The specimens were all planed exactly 2·5 inches wide and placed upon supports 10 inches apart. The testing was done in Mr. Kirkaldy's testing machine, the stress being applied at the centre of the strips by means of a ram, shaped thus 

at the end, moved very slowly by hydraulic power.

The strips having been bent by the above method to the shape in the figure they were further bent by being compressed in the machine as shown by the arrows. The bending was continued in each case until the specimen was bent through an angle of 180° and closed over a bar twice the thickness of the plate, unless it cracked or broke before that stage.



As the plates were bent by a stress applied at the centre they were thus in the position of beams supported at the ends and loaded at the centre. It is usually considered that the stress in such cases varies as the square of the depth, or in this case the thickness of the plate. In the following table a comparison is made between the mean actual ultimate stresses given in table 9 for the lengthway strips and the stresses calculated upon the above hypothesis, taking the ¼-inch plate as the basis of comparison :—

Nominal Thickness of Plate.	Actual Ultimate Stress.	Calculated Stress assuming the Resistance to vary as the Square of the Thickness.	Difference between the Actual and Calculated Stress.
	lbs.	lbs.	lbs. per cent.
¼ inch -	1,124	1,124	nil nil.
½ - -	4,370	5,063	693=15·8
¾ - -	10,766	11,102	336= 3·1
1 - -	17,730	18,538	808= 4·5

It will seen from the above that the stresses vary very nearly as the square of the thickness, the only deviation therefrom of any practical moment being in the case of the ½-inch plates, in which the mean actual stress is 15·8 per cent. less than the calculated stress.

The following table gives the mean stresses borne by the lengthway and crossway specimens tested in the same condition as received :—

Nominal Thickness of Plate.	Ultimate Stress.			
	Lengthway as received.	Crossway as received.	Difference in favour of Lengthway.	Difference in favour of Crossway.
	lbs.	lbs.	lbs. per cent.	lbs. per cent.
$\frac{1}{4}$ inch - -	1,124	1,092	32 = 2·8	—
$\frac{1}{2}$ " - -	4,370	4,438	—	68 = 1·5
$\frac{3}{4}$ " - -	10,766	11,145	—	379 = 3·5
1 " - -	17,730	17,350	380 = 2·1	—
			Mean 2·45	Mean 2·

The mean results are thus very nearly equal, the stresses of the $\frac{1}{4}$ and 1 inch plates being in favour of the lengthway and of the $\frac{1}{2}$ and $\frac{3}{4}$ inch in favour of the crossway.

In the following table a comparison is made between the stresses borne by the lengthway and crossway specimens tested in the condition received, and also after having been heated to a cherry red and cooled in water :—

Nominal Thickness of Plate.	Ultimate Stress.					
	Lengthway as received.	Lengthway Heated and Cooled in Water.	Increase of Resistance due to Heating and Cooling.	Crossway as received.	Crossway Heated and Cooled in Water.	Increase of Resistance due to Heating and Cooling.
inch.	lbs.	lbs.	lbs. per cent.	lbs.	lbs.	lbs. per cent.
$\frac{1}{4}$	1,124	1,145	21 = 1·8	1,092	1,117	25 = 2·2
$\frac{1}{2}$	4,370	4,573	203 = 4·6	4,438	4,563	125 = 2·8
$\frac{3}{4}$	10,766	11,908	1142 = 10·6	11,145	11,974	829 = 7·4
1	17,730	19,742	2102 = 11·3	17,350	20,366	3016 = 17·3
			mean 7·0			mean 7·4

It thus appears that after being tempered as above the stresses required to bend the lengthway specimens $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1-inch thick are increased 1·8, 4·6, 10·6, and 11·3 per cent. respectively, and for the crossway specimens 2·2, 2·8, 7·4, and 17·3 per cent. respectively, the total mean increase for the lengthway and crossway specimens being thus 7·0 and 7·4 per cent. respectively.

Respecting the specimens tested in the same condition as received, better results, as regards the angles to which they could be bent, were obtained with the lengthway than with the crossway, one of the former, however, $\frac{1}{2}$-inch thick, cracked slightly when bent to an angle of 180°, and one $\frac{3}{4}$-inch thick broke at an angle of 140°, the remainder were uninjured by the test. Of the crossway specimens, only two withstood the test uninjured, the others did not give way until bent to a considerable angle. These results prove that the lengthway strips bear bending better than the crossway; the fact is worthy of attention since it has been shown in a previous section that the mean contraction of area at fracture of the steel plates, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1-inch thick lengthway and crossway, are respectively 49·1 and 40·3 per cent. The difference is not very great, but would appear to account for the better results obtained with the lengthway strips.

Of the specimens which were heated to a cherry red and cooled in water, three only of the lengthway (two of them $\frac{1}{4}$ and one $\frac{1}{2}$ inch thick) bore bending to 180° without injury. As might have been expected from the previous results, the ability of the lengthway strips to bear bending being injuriously affected by their being heated and cooled in water, this effect was much more marked in the case of the crossway specimens. None of the latter which had been heated to a cherry red and cooled in water bore the bending tests without injury.

The results of the bending test in tables 9 and 17 as regards the angles to which the plates bent without injury cannot be regarded as coming up to the high standard which the Steel Company of Scotland claim for their steel. Upon receiving the results of these experiments they stated that they did not regard them as satisfactory, as they were far from being equal to the results daily obtained with a large number of strips tested at their works, and they expressed a desire that a visit should be paid there in order that the results of the bending and tempering tests as carried out by themselves might be witnessed. This was accordingly done, the tempering and bending of all specimens so treated were witnessed, the specimens being heated to a cherry red and cooled suddenly in water at a temperature of about 80° Fahrenheit. The system adopted by Mr. Kirkaldy in bending the strips has already been described. The Steel Company of Scotland adopt a different plan, the plates being first bent by a swage of large curvature in the apparatus shown in Fig. 1 or 2, Plate 1, and afterwards bent double by light blows from a steam hammer.

In the Appendix will be found the particulars of the tests carried out; only the results of testing the specimens which were planed out of the plates, and with the edges left sharp, can fairly be compared with those tested by Mr. Kirkaldy. Some planed specimens with the edges slightly rounded were tested as a matter of scientific interest, in order to show the greater closeness to which they could be bent, than when the edges were left sharp. Other pieces which were sheared from the plate were tested in order to show the ability of the steel to stand bending when so treated, in accordance with the usual plan at the works. A reference to the particulars of the tests will, it is thought, be convincing that the material when bent in the apparatus used by the Steel Company of Scotland will stand bending better than as shown by Tables 9 and 17.

The care bestowed by Mr. Kirkaldy in testing is always so great as to preclude all idea of the specimens being unfairly treated either in heating, or bending, so that there is apparently no other explanation than that the plan adopted by the Steel Company of Scotland for bending specimens by the swage and hammer, can be made more lenient to the material than that adopted by Mr. Kirkaldy. It may, indeed, be stated that since these experiments were made additional confirmation has been given in other quarters of the truth of this fact.

There can be no doubt that Mr. Kirkaldy's system of bending is scientifically the more accurate, and admits of so much greater regularity of treatment that it is much to be preferred generally, as all that uncertainty is obviated which must exist with the other method, respecting the heaviness of the blows struck.

Some interesting bending tests were also made of ships' angles, two of them steel and two iron; the full particulars will be found in the Appendix numbered 142 to 145. In the first experiment on one of the steel angles it was first flattened out under the steam hammer, then gripped between the hammer and anvil and bent double. In the second experiment the steel angle was flattened out in the same way as the first, and then bent back on to the ridge. In the third experiment, which was with an iron angle, it showed signs of cracking when it had opened out ½ inch, and finally gave way suddenly the whole length. In the fourth experiment the iron angle gave way suddenly the whole length when attempting to flatten it. The results showed the great superiority of the steel angles as compared with iron angles under the above treatment.

In order that the bending of the steel plate might be compared with that of iron, 48 iron specimens were tested in a similar way. They were cut from plates of six different brands, about half the number being sheared from the plates, and the remainder planed. The particulars of the experiments are given in the Appendix, and abundantly prove the great superiority of the steel plates over the iron ones for bending. The injurious effects of shearing the specimens off the plates as compared with planing is clearly shown by the earlier fractures when bent.

In addition to the bending and tempering tests referred to, the Steel Company of Scotland carried out some experiments to ascertain the effect of heating steel plates to the temperature of boiling tallow, and bending them in that condition. For purposes of comparison pieces were planed from the same plates and bent cold. The particulars of the experiments, all of which were witnessed, will be found in the Appendix; the specimens were numbered 160 to 201, and consisted of plates from ¼ to 1 inch thick.

They were all bent in the apparatus, Fig. 2, Plate 1, and further bent and finally closed under the steam hammer. Of those bent cold all but three, which cracked slightly when the prescribed test was reached or exceeded, bore the operation without injury, but all which were bent when heated to the temperature of boiling tallow cracked or broke. These experiments illustrate forcibly the injurious results of working steel plates at the above temperature. The same effects, it may be stated, have been observed with iron, as well as with the steel made by other manufacturers when similarly treated. The matter is of great importance in the usual operations of the shipbuilder and engineer, and may doubtless account for cases of unexpected fracture, owing to such metals having been injured by being worked at temperatures which caused a reduction in their strength or ductility.

The plates of superheaters, when enclosed wholly or partly in the uptakes, are often heated to a temperature equal or exceeding that which has been found to affect the steel so prejudicially, and in the absence of a full series of experiments to ascertain the exact loss of the tensile or crushing resistance, it is prudent either to dispense with such structures; or efficiently protect them by shield plates from the contact of flame or hot gases.

There is no branch of experimental inquiry into the properties of steel and iron which better merits attention than the effect of different temperatures upon their mechanical properties, and it is much to be desired that a set of experiments at temperatures ranging from the ordinary temperature of the atmosphere up to about 1,000° Fahrenheit, were carried out by the different manufacturers interested in the manufacture and application of steel and iron. Indeed, until this is done those charged with the designing or supervision of machinery will always have doubts of the suitability of steel when its temperature is liable to become moderately high.

RESPECTING the RESULTS of EXPERIMENTS made upon STEEL PLATES to ascertain the effects of BULGING STRESS; ALSO the EFFECTS of DRIFTING.

Table 10 contains the results of experiments made by Mr. Kirkaldy to ascertain the effects of bulging stress upon steel plates. The object of these experiments was chiefly to ascertain the behaviour of the steel when subject to the strain it would receive under the circumstances of a vessel taking the ground and resting upon a stone or point of rock. The specimens, of which two of each thickness were tested, consisted of discs 12 inches diameter which were pressed into apertures 10 inches diameter. The mean force required in the case of the $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ inch plates were 84,335 lbs., 187,055 lbs., and 338,225 lbs. respectively.

The bulging stresses of the $\frac{1}{4}$ and $\frac{1}{2}$ inch steel plates vary nearly directly as the thickness, but with the $\frac{3}{4}$-inch plates the stress increased at a more rapid rate. All the $\frac{1}{4}$ and $\frac{1}{2}$ inch discs bore the bulging without injury, but the $\frac{3}{4}$-inch discs cracked.

Four additional experiments were made at the works of the Steel Company of Scotland, in order further to illustrate the capability of this steel to sustain bulging, and to compare with the behaviour of iron when similarly treated. The particulars of the experiments are given in the Appendix numbered 138 to 141. The plates, four in number, were 10½ inches diameter, two being steel and two iron. They were forced into a ring 7⅜ inches diameter by means of a steam hammer and punch, as shown in Fig. 3, Plate 1. In the case of the steel discs they were dished to a depth of 3¼ inches without injury, whilst the iron plates broke badly when dished 2 inches and 2¼ inches respectively.

Reference may appropriately be made here to the behaviour of a steel and iron plate when subject to explosive force. Fig. 1, Plate 2, is a sketch of a steel plate ⅜-inch thick, upon which were exploded five cartridges of dynamite weighing in all 13 ozs., and which although bulged at the centre to a depth of about 11 inches showed no signs of cracking. Fig. 3, is a sketch of an iron plate, branded* " ——— best" upon which were exploded three dynamite cartridges, which caused the effects shown. The entire destruction of the iron plate with a charge of three fifths of that which was borne without cracking by the steel plate indicates very clearly the inferiority of the iron plate when subjected to a test of this character.

In the Appendix will be found some very interesting experiments made at the works of the Steel Company of Scotland, in order to ascertain the effects of drifting. Plate 3 shows the taper of the six drifts employed. In the centre of each piece of plate experimented upon was a ¾-inch hole, which was either drilled, punched, or punched and afterwards bored out to 1 inch.

The particulars of the experiments are given in the Appendix numbered 146 to 159, by which it will be seen that no cracks appeared until a very considerable enlargement of the holes had taken place. Cracks appeared earlier in the punched plates than in those drilled, although the difference was not so great as might perhaps have been anticipated.

Six pieces of iron plate the same size and thickness, in each of which was a ¾-inch hole, were also experimented with. The holes were respectively drilled, punched, and punched and afterwards bored to 1 inch in one specimen of each thickness. It is not fair to compare the effects of drifting in the ⅝-inch plate as no steel plates of that thickness were experimented with, but in the case of the ½-inch plate it was found that upon the application of the drift the plate cracked with a very much smaller increase in the size of hole than occurred with the steel plates. The injurious effects of drifting upon iron plates, long known to engineers and shipbuilders, has led to the most careful and well-informed forbidding its use. The fact of this steel bearing the application of the drift to a much greater extent than iron without cracking, is no doubt a valuable property, but the use of the drift in ship and boiler work should none the less be rigidly prohibited. The experiments which have been made upon the tensile strength and elongation of the steel when punched have shown the thicker plates to suffer considerably. To what extent the tensile strength of the steel may be further reduced by the action of the drift is a very appropriate subject for further experimental inquiry, but judging from what is known of the properties of mild steel generally, the use of the drift should as with iron be forbidden.

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* This is a Glasgow brand.

RESPECTING the RESULTS of TESTING by HYDRAULIC PRESSURE Boxes made of Steel Plate, representing the Flat Surfaces of Steam Boilers.

In addition to the experiments already referred to, it was considered desirable to carry out a further series in order to ascertain the strength of steel plate under pressure, when worked into the flat surfaces of steam boilers, and supported in the different ways commonly adopted. The Steel Company of Scotland very liberally consented to defray the additional expense of making and testing eight experimental boxes made to represent (1), the flat surfaces of combustion chambers, having the stays screwed through the plates and the ends riveted over to form substantial heads; (2), the flat surfaces of combustion chambers having the stays screwed through the plates and fitted with nuts on the outside; (3), the ends of boilers in the steam space, the stays being fastened to the plate by nuts on each side; and (4), the same as No. 3, but the plate in way of the stays strengthened by large plate washers riveted on, the stays passing through the centre. The construction and details of the different boxes, together with sketches showing the appearances of the plates after the experiments, are given in plates 4, 5, 6, 7, and 8. The boxes in series 1 and 2 were made by the Hamilton's Windsor Ironworks Company, Garston. They were constructed of steel plates of the nominal thickness $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ inch, but the actual thicknesses were $\frac{9}{32}$, $\frac{13}{32}$, and $\frac{1}{2}$ inch. The backs of the boxes were formed of wrought iron plate 1 inch thick, and the frames were of cast iron. The plates were supported by 16 stays spaced 8 inches apart each way, this large number being adopted in order that the bulges and permanent sets might be obtained of portions of plate unaffected by the sides of the boxes. The stays were of iron $1\frac{1}{2}$ inches diameter, and screwed twelve threads to the inch.

In the construction of these experimental boxes in series 1 and 2, and in carrying out the experiments with them, there was afforded the very valuable co-operation of Mr. Sharrock, manager of the Hamilton's Windsor Ironworks, and formerly assistant manager to the late Sir William Fairbairn.

Four strips, two lengthway and two crossway, were cut from each plate and tested by Mr. Kirkaldy for tensile strength and elongation; the results are given in Table 12. The mean ultimate tensile strength lengthway of the $\frac{9}{32}$, $\frac{13}{32}$, and $\frac{1}{2}$ inch plates being found to be respectively 30·65, 29·5, and 29·4 tons; and crossway 30·15, 29·25, and 28·75 tons per square inch. The elongation lengthway in 10 inches—23·5, 28·7, and 27·5 per cent., and crossway 18·7, 23·35, and 27·2 per cent. These results show the material to be similar in character to the plates used in the experiments already dealt with, but rather harder than is usually employed in the construction of combustion chambers.

Whilst under test the boxes were placed on their edges, and at about 2 inches from the surface of the plate a flat bar was fixed across the centre of the box, with its ends resting on the planed surface of the cast-iron frame. Three movable gauges Γ shaped in section, with a slot in one flange, were each connected to the crossbar opposite the centres of the spaces marked B, E, and H, by a couple of studs, which allowed the gauges to move freely endways. One flange was used for recording the bulges, and the other the permanent sets.

The pressures were indicated by two high-pressure gauges specially made for this department by Messrs. John Dewrance and Co., Great Dover Street, London.

Before the commencement of the experiment a zero or base line, from which the bulges and permanent sets were respectively measured, was marked on each side of the gauge in line with the outer edge of the crossbar. The pressure was slowly and steadily applied by a force pump, and at each increase of pressure of 25 lbs. or 50 lbs. per square inch, the pumping was stopped, and the bulge of the plate recorded by a line drawn on the gauges with the point of a sharp knife. The pressure having been allowed to remain on for about two minutes, it was then lowered to zero, the gauges pushed back against the plate, and the permanent sets marked in a similar way to the bulges. This plan was carried out until the conclusion of the experiments.

The boxes with the riveted stays were first tested. The following table gives the particulars obtained with the $\frac{9}{32}$-inch box, as recorded in the manner described:—

EXPERIMENTAL BOX No. 1. Plate 4.

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{9}{32}$-inch Steel Plate supported by fine-threaded Stays $1\frac{1}{2}$ inches diameter screwed into the Plate and riveted over. Stays spaced 8 inches × 8 inches.

Pressure per Sq. In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
50	·015	·015	·015	Nil	Nil	Nil	At 300 lbs. sounds from inside of box like wood cracking. After pressure was reduced found the heads of four stays cracked, and radial lines at plate round stays.
100	·03	·03	·03	,,	,,	,,	
150	·05	·04	·05	,,	,,	,,	
200	·06	·05	·06	·005	·005	·005	
250	·10	·09	·09	·025	·025	·015	
300	·33	·42	·32	·26	·35	·22	At 350 lbs., after keeping pressure on for half a minute, the riveted heads of stays, Nos. 6, 7, 10, and 11 broke off with a loud report, and the plate was forced away from the stays. All the other stay heads except the corner ones cracked.
350	—	—	—	—	—	—	

A bulge unaccompanied by permanent set was observed at 50 lbs. per square inch, and it increased at a comparatively uniform rate with the increase in the pressure until 200 lbs. was applied, when a slight permanent set was recorded. Above this, the bulges and permanent sets increased at a much more rapid rate than the increments of pressure, especially above 250 lbs., until at 350 lbs. per square inch the box gave way with a loud report, as described in the column of remarks.

The box in this case failed in a similar manner to some wrought-iron experimental boxes which were tested in London about six years ago for the information of the Board of Trade staff; the stretching of the plate being concentrated near the stay holes, reduced the hold of the plate on the threads of the stays, and caused a greatly increased strain upon the riveted heads, which, being insufficient to sustain it, broke off, the plate slipping off the stays, the threads of stay and hole being almost uninjured.

The following table gives the particulars of bulges and permanent sets of the $\frac{13}{32}$-inch box with riveted stays:—

EXPERIMENTAL BOX No. 2. Plate 4.

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{13}{32}$-inch Steel Plate supported by fine-threaded Stays 1½ inches diameter screwed into the Plate and riveted over. Stays spaced 8 inches × 8 inches.

Pressure per Sq. In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
25	·005	·005	·005	Nil	Nil	Nil	At 375 lbs. cracking sounds from inside box. At 425 lbs. cracking sounds much increased. At 475 lbs. four centre stay heads practically cracked through. At 495 lbs. the head of No. 7 stay flew off, and the plate slipped over the stay. The heads of the other three centre stays practically broken through.
75	·01	·01	·01	„	„	„	
125	·015	·015	·015	„	„	„	
175	·025	·020	·020	„	„	„	
225	·035	·025	·03	„	„	„	
275	·04	·03	·035	„	„	„	
325	·05	·035	·04	·005	·005	·005	
375	·07	·04	·06	·025	·025	·02	
425	·10	·07	·08	·05	·06	·04	
475	·38	·12	·30	·35	·47	·24	
495	—	—	—	—	—	—	

In this case also a slight bulge was observed at a very low pressure. It was found, as in the previous experiment, that the bulges increased at a comparatively uniform rate until a permanent set was recorded, which was at 325 lbs. per square inch. Above this pressure both increased rapidly until a large increase in the permanent set took place at 475 lbs. per square inch, the box giving way with a further additional pressure of 20 lbs. per square inch by the riveted head of one of the centre stays breaking off, and the plate slipping over the stay end. The riveted heads of the other centre stays were also practically destroyed. The particulars of the experiment with the ½-inch box with riveted stays are next given.

EXPERIMENTAL BOX No. 3. Plate 4.

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{1}{2}$-inch Steel Plate supported by fine-threaded Stays $1\frac{1}{2}$ inches diameter screwed into the Plate and riveted over. Stays spaced 8 inches × 8 inches.

Pressure per Sq.In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
50	Nil.	Nil	Nil	Nil	Nil	Nil	At 540 lbs. cracking sounds from inside box. At 700 lbs. stay heads Nos. 3 and 6 slightly cracked; No. 7 much cracked. At 740 lbs. the head of No. 7 stay broke off, and the plate slipped over the stay end; head of No. 6 stay cracked all round, and those of Nos. 10 and 11 slightly cracked.
100	·005	·005	·005	„	„	„	
150	·010	·010	·010	„	„	„	
200	·010	·015	·010	„	„	„	
250	·015	·020	·015	„	„	„	
300	·015	·025	·015	„	„	„	
350	·020	·027	·020	„	„	„	
400	·025	·030	·025	„	„	„	
450	·035	·035	·080	„	„	„	
500	·04	·04	·035	„	„	„	
550	·045	·045	·04	·005	·005	·005	
600	·05	·05	·05	·02	·03	·025	
650	·08	·08	·08	·04	·06	·045	
700	·31	·86	·20	·27	·35	·16	
740	—	—	—	—	—	—	

The $\frac{1}{2}$-inch box thus gave way in a similar way to the $\frac{9}{32}$ and $\frac{13}{32}$-inch, by the stretching of the plate at the centre stays. The riveting of the centre stays gave way first, owing to the bulging of the plate in their vicinity being greater than at other parts where affected by the support afforded by the sides of the box. It is this fact which necessitates the fitting of a considerable number of stays in these experimental boxes, in order that the conditions under pressure may be the same as in the combustion chamber of a boiler, in which there are usually a large number of stays. In cases where this has not been recognised, and a small number of stays only fitted in experimental boxes, the results of the experiments have not been entirely satisfactory, the bursting pressure appearing to be higher than would occur with a combustion chamber of the same thickness and similarly stayed.

The pressures at which the $\frac{9}{32}$, $\frac{13}{32}$, and $\frac{1}{2}$-inch boxes failed are 350 lbs., 495 lbs., and 740 lbs. respectively, but from the previous rapid increase in the bulges and permanent sets it is evident that the plates were practically *hors de combat* at much less than the bursting pressures.

As it is desirable to make a comparison not only between the pressures at which the boxes burst, but also between those at which the elastic limit was reached, curves have been constructed (see Plate 9) showing the permanent sets at the different pressures. Referring to these curves, and also the particulars of the bulges and permanent sets given in the tables, it will be seen that they increase at a comparatively uniform rate until a pressure is reached at which they are found to increase much more rapidly. This point may be regarded as the elastic limit, or if not the elastic limit it affords a fair position for comparison.

The second series of experiments respecting the strength of flat surfaces was made with three boxes constructed of steel plates, $\frac{9}{32}$, $\frac{13}{32}$, and $\frac{1}{2}$ inch thick, supported by stays spaced 8 inches apart each way, screwed into the plate and secured by nuts on the outside.

The following are the results obtained with the $\frac{9}{32}$-inch box:—

Experimental Box No. 4. Plate 5.

Results of Testing by Hydraulic Pressure a Box made of $\frac{9}{32}$-inch Steel Plate supported by fine-threaded Stays $1\frac{1}{2}$ inches diameter, screwed into the Plate and fitted with nuts on the outside. Stays spaced 8 inches × 8 inches.

Pressure per Sq.In.	Bulge.			Permanent Set.			Permanent Lengthening of Stays.				Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	No. 6.	No. 7.	No. 10.	No. 11.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
50	·01	·01	·01	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
100	·03	·03	·03	"	"	"	"	"	"	"	
150	·05	·05	·05	"	"	"	"	"	"	"	
200	·06	·06	·06	·03	·02	·03	"	"	"	"	
250	·10	·10	·10	·04	·04	·04	"	"	"	"	
300	·15	·15	·15	·08	·09	·08	"	"	"	"	
350	·25	·25	·24	·17	·19	·16	"	"	"	"	At 350 lbs. plate began to show radial lines round the stays.
400	·35	·35	·34	·28	·29	·27	"	"	"	"	
450	·43	·41	·42	·36	·37	·36	"	"	"	"	
500	·49	·46	·48	·43	·43	·42	"	"	"	"	
550	·54	·50	·53	·49	·48	·49		"	"	"	
600	·59	·55	·58	·54	·53	·54	"	"	"	"	600 lbs.—First leak at stays perceived.
650	·63	·59	·62	·59	·56	·58	"	"	"	"	650 lbs.—Considerable leak at joint.
700	·68	·65	·67	·62	·60	·62	"	"	"	"	700 lbs.—Stays Nos. 6, 7,10, 11, leaking badly. Obliged to tighten up stays at this pressure.
750	·74	·68	·73	not taken	not taken	not taken	"	"	"	"	750 lbs.—Joint very leaky. Joint remade with jam nuts at back. Sets taken with 400 lbs. pressure per square inch on box during remainder of experiment.
750	·74	·68	·73	·74	·69	·73	"	"	"	"	
800	·75	·71	·76	·75	·70	·75	"	"	"	"	
850	·77	·73	·78	·77	·74	·78	·015	·015	·05	·03	
900	·83	·80	·84	·83	·79	·84	·05	·015	·06	·05	
950	·87	·87	·88	·87	·86	·88	not taken	not taken	not taken	not taken	
980	not taken	not taken	·93	not taken	not taken	·90	·05	·03	·06	·05	980 lbs.—Plate cracked at No. 7 stay.

At 750 lbs. per square inch, stayholes Nos. 1, 4, 13, 16, permanently enlarged $\frac{3}{32}$ inch.
At 980 lbs. " " " " " " " " $\frac{5}{32}$ inch.
At 750 lbs. " " 2 3, 5, 8, 9, 12, 14, 15, " " $\frac{1}{8}$ inch.
At 980 lbs. " " " " " " " " " " $\frac{1}{4}$ inch.
At 750 lbs. " " 7, 10, 11, " " $\frac{7}{32}$ inch.
At 980 lbs. " " " " " " " " $\frac{7}{16}$ inch.

The Table shows that a permanent set was observed at the same pressure as with the $\frac{9}{32}$-inch box with riveted stays, and that the plate was heavily strained at 350 lbs. per square inch. Upon the pressure being allowed to fall to zero after the application of 750 lbs. pressure that the permanent set might be ascertained, the plate sprung back from the nut, it having stretched so much at the stay holes as to allow it to pass over the threads of the stays. Upon again applying the pressure the pump could not overcome the leakage and force the plate up against the nuts. For all practical purposes the box at this stage, and even earlier, was *hors de combat* in consequence of the stretching of the plate at the stay holes, but as it was very important to ascertain whether it was possible to crack the plate the joint was re-made with jam nuts on the stays at the back of the plates, and the pressure was again applied, the box ultimately failing at a pressure of 980 lbs. per square inch by the plate cracking at one of the centre stays. During the latter part of the experiment the continued stretching of the plate at the stay holes, and the leakage at the stays when the pressure was reduced, rendered it necessary, in order to obviate the re-making of the joint, after every increment of pressure, to take the permanent sets with a pressure of 400 lbs. per square inch on the box.

At the higher pressures there was a perceptible lengthening of the centre stays as recorded in the table, the permanent sets should therefore be reduced by about the mean of the extensions given. At the bottom of the table the extent to which the stay holes increased in size is given at pressures of 750 lbs. and 980 lbs. per square inch. The results are interesting as confirming what has been remarked respecting the greater bulging of the plate at the centre. The stay holes which are least enlarged are, as might be anticipated, those at the corners of the box.

The following tables contain the results of testing the $\frac{13}{32}$ and $\frac{1}{2}$ inch boxes having the stays screwed through the plates and fitted with nuts on the outside :—

EXPERIMENTAL BOX No. 5. Plate 5.

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{13}{32}$-inch Steel Plate, supported by fine-threaded Stays $1\frac{1}{2}$ inches diameter, screwed into the Plate and fitted with nuts on the outside. Stays spaced 8 inches × 8 inches.

Pressure per Square Inch	Bulge.			Permanent Set.			Permanent Lengthening of Stays.				Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	No. 6	No. 7.	No. 10.	No. 11.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
50	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
100	·005	"	"	"	"	"	"	"	"	"	
150	·01	·005	·01	"	"	"	"	"	"	"	
200	·02	·01	·02	"	"	"	"	"	"	"	
250	·03	·02	·03	"	"	"	"	"	"	"	
300	·04	·03	·04	·01	·01	·01	"	"	"	"	
350	·06	·05	·06	·02	·02	·02	"	"	"	"	
400	·10	·09	·09	·04	·05	·04	"	"	"	"	
450	·14	·15	·13	·08	·10	·08	"	"	"	"	
500	·24	·23	·23	·18	·20	·17	"	"	"	"	
550	·33	·32	·32	·28	·29	·27	"	"	"	"	550 lbs.—Radial lines round stays on plate.
600	·41	·37	·40	·37	·36	·36	"	"	"	"	
650	·47	·44	·46	·44	·42	·43	"	"	"	"	
700	·55	·49	·54	·51	·49	·50	"	"	·015	"	
750	·59	·52	·56	·54	·51	·54	"	"	·015	"	
800	·62	·55	·61	·59	·55	·59	·015	·015	·03	"	
850	·67	·60	·66	·64	·59	·64	·015	·03	·05	·015	
900	·72	·65	·71	·68	·64	·69	·05	·05	·06	·05	
950	·77	·69	·76	·73	·70	·74	not taken	not taken	not taken	not taken	950 lbs.—After the pressure was taken off, leaks were found at all the stay nuts.
1000	·83	·76	·82	·79	·76	·79	·09	·22	·12	·06	
1050											1,050 lbs.—Could not get this pressure on owing to leakage at stays. Joint re-made, and stays re-grummeted.
1050	·86	·80	·85	not taken	not taken	not taken	not taken	not taken	not taken	not taken	
1100	·87	·84	·86	"	"	"	"	"	"	"	
1150	·93	·89	·92	"	"	"	"	"	"	"	
1200											1,200 lbs.—With this pressure, stays Nos. 6, 7, 10, and 12 broke off under nuts.

EXPERIMENTAL BOX No. 6. Plate 5.

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{1}{2}$-inch Steel Plate supported by fine-threaded Stays $1\frac{1}{4}$ inches diameter screwed into the Plate and fitted with Nuts on the outside. Stays spaced 8 inches × 8 inches.

Pressure per Sq. In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
25	Nil	Nil	Nil	Nil	Nil	Nil	
100	”	”	”	”	”	”	
200	”	”	”	”	”	”	
250	”	”	”	”	”	”	
300	”	”	”	”	”	”	
350	”	”	”	”	”	”	
400	”	”	”	”	”	”	
450	·01	·01	·01	”	”	”	
500	·04	·04	·03	”	”	”	
550	·05	·05	·04	·01	·01	·01	
600	·06	·06	·06	·03	·03	·03	
650	·08	·08	·08	·04	·06	·05	
700	·13	·13	·13	·08	·10	·08	
750	·19	·18	·15	·13	·16	·14	
800	·26	·27	·23	·20	·23	·21	800 lbs.—Began to leak at stays and at joint.
850	·32	·33	·30	·27	·30	·27	
900	·38	·40	·38	·35	·39	·35	850 lbs.—Leak gradually increasing.
950	·42	·44	·41	·37	·42	·37	
1,000	·48	·50	·47	·42	·47	·42	900 lbs.—Leak increasing.
1,050	·53	·55	·53	·49	·54	·49	950 lbs.—Tightened and caulked joint, but still leaky.
1,080	not taken	not taken	not taken	not taken	not taken	not taken	1,000 lbs.—Leak much increased.
1,100	·57	·60	·55	·53	·58	·53	1,050 lbs.—Could not get higher pressure owing to great leakage at joint and stays; joint was re-made.
1,150	·62	·68	·62	·59	·70	·60	
1,200	·68	·77	·70	·65	·75	·66	
1,250	·78	·87	·80	·72	·82	·73	
1,300	·87	·96	1·10	·78	·93	·83	1,300 lbs.—At this point stays 15 and 16 broke and No. 12 stay stripped.

The $\frac{13}{32}$ and $\frac{1}{2}$ inch boxes last tested thus gave way by the breakage of stays. Although the plates had practically failed from leakage long before the stays broke, the ultimate strength of the plate was undetermined. The Steel Company of Scotland had so liberally borne the large expense incurred in carrying out these and previous experiments, that a great indisposition was felt to request them to do any more, and the experiments would probably have remained unfinished had not Mr. Thomas Adams, of the works of the "Ant and Bee," Manchester, most liberally offered to bear the expense of making and testing some additional experimental boxes. Mr. Adams' offer was gladly accepted, three additional experimental boxes made of steel plates, $\frac{13}{32}$, $\frac{15}{32}$, and ½-inch thick, being made and tested at his works. The stays were screwed into the plates and fitted with nuts on the outside. In the former boxes the stays were iron, 1½ inches diameter, but in these they were made of steel 2 inches diameter, in order to ensure their not breaking before the plate was destroyed. The nuts were 2 inches thick, and in order that the plate might not receive more support from them against bulging than would be given in practice, they were turned down, where in contact with the box, to the size of a 1½-inch nut across the angles. The following results were obtained during the tests by hydraulic pressure :—

EXPERIMENTAL BOX No. 7. Plate 6.

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{13}{32}$-inch Steel Plate supported by fine-threaded Stays 2 inches diameter screwed into the Plate and fitted with Nuts. Stays spaced 8 inches × 8 inches.

Pressure per Sq. In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
100	·01	·01	·01	Nil	Nil	Nil	500 lbs.—Scale falling off plate, hissing sounds being emitted. Set taken at this and higher pressures with 100 lbs. per square inch on the box. 1,200 lbs.—Plate touching the corners of the four middle stay nuts. Took off the nuts and bevelled the corners. Again applied pressure, and when gauge indicated 1,100 lbs. the plate slipped over the round portion of the nuts of the four centre stays. Further test abandoned.
200	·03	·02	·02	„	„	„	
300	·04	·04	·04	„	„	„	
400	·06	·06	·05	·01	·01	·01	
500	·21	·26	·18	·16	·22	·14	
600	·40	·47	·40	·38	·45	·38	
700	·51	·57	·52	·49	·55	·50	
800	·61	·66	·63	·60	·64	·61	
900	·69	·78	·78	·68	·78	·76	
1,000	·76	·84	·82	·75	·83	·81	
1,100	·84	·88	·87	·84	·87	·87	
1,200	·90	·92	·92	·90	·92	·92	

EXPERIMENTAL BOX No. 8. Plate 6.

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{15}{32}$-inch Steel Plate supported by fine-threaded Stays 2 inches diameter screwed into the Plate and fitted with Nuts. Stays spaced 8 inches × 8 inches.

Pressure per Sq. In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	A pressure of 100 lbs. per square inch was applied to test the joints before the experiment commenced. 700 lbs.—Scale falling off the plate near the stay holes. 800 lbs. and 900 lbs.—The set was taken with 100 lbs. per square inch on box. 1,000 lbs.—At this and higher pressures the set was taken with 200 lbs. on box. 1,400 lbs.—Leak at stay head; gauges oscillating 50 lbs.; when the stay was partially unscrewed to receive a new grummet, the pressure fell to zero, and the plate started back about $\frac{1}{16}$ inch from the stay nuts. Fitted new grummets under the four centre stay nuts and re-set gauges. 1,550 lbs.—Plate slipped over No. 7 stay nut. Further test abandoned.
100	·01	·01	line	Nil	Nil	Nil	
200	·02 bare	·02	·01	”	”	”	
300	·02	·02 full	·02	”	”	”	
400	·03	·03	·03	”	”	”	
500	·04	·05	·04	·03	·02	·02	
600	·10	·17	·14	·07	·15	·12	
700	·34	·44	·40	·33	·42	·38	
800	·48	·54	·54	·46	·53	·52	
900	·57	·62	·62	·55	·60	·60	
1,000	·67	·69	·70	·66	·67	·69	
1,100	·74	·75	·78	·73	·73	·76	
1,200	·80	·82	·84	·80	·81	·83	
1,300	·86	·86	·89	·86	·85	·89	
1,400	·92	·93	·96	·92	·92	·96	
1,500	1·21	1·25	1·20	1·21	1·25	1·19	
1,550	—	—	—	—	—	—	

EXPERIMENTAL Box No. 9. Plate 6.

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of ½-inch Steel Plate supported by fine-threaded Stays 2 inches diameter screwed into the Plate and fitted with Nuts. Stays spaced 8 inches × 8 inches

Pressure per Sq. In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch	Inch.	
100	·01	Nil	·01	Nil	Nil	Nil	700 lbs.—At this, and higher pressures the set was taken with 100 lbs. per square inch on the box. 1,950 lbs. — When reducing the pressure to take set, the plate sprang back from the nuts of Nos. 6, 7, 10, and 11 stays about 1/16 of an inch. Put fresh grummets under these nuts. 2,000 lbs.—Thread of No. 6 stay stripped. Turned ½ inch off the inside of the stay heads to bring points of bolts through the nuts. Fitted new stay in lieu of No. 6 stay. When 2,000 lbs. was again applied the plate slipped over the nut of No. 11 stay.
200	·01	·01	·02	,,	,,	,,	
300	·02	·01	·02	,,	,,	,,	
400	·03	·02	·03	,,	,,	,,	
500	·04	·03	·04	,,	,,	,,	
550	·04	·03	·05	,,	,,	,,	
600	·04	·03	·05	,,	,,	,,	
650	·05	·04	·07	·02	·02	·03	
700	·07	·06	·12	·05	·03	·09	
750	·12	·10	·21	·09	·08	·17	
800	·24	·24	·36	·23	·22	·32	
850	·36	·35	·46	·34	·32	·41	
900	·42	·41	·51	·41	·38	·47	
950	·50	·45	·56	·48	·44	·54	
1,000	·53	·48	·60	·52	·46	·58	
1,050	·56	·50	·63	—	—	—	
1,100	·60	·52	·66	—	—	—	
1,150	·62	·55	·69	—	—	—	
1,200	·64	·56	·72	·63	·55	·72	
1,250	·67	·58	·75	·66	·58	·74	
1,350	·70	·61	·78	·70	·61	·78	
1,750	·90	·81	1·02	·89	·81	1·00	
1,950	1·06	1·00	1·16	—	—	—	
2,000	—	—	—	—	—	—	

The following summary contains the results of the different experiments:—

No. of Experimental Box.	Thickness of Plate.	Description.	Pressure per Square Inch at which the Box failed.	How Failed.
1	h	Stays screwed through plate and riveted over.	Lbs. 350	Riveted heads broke off and plate forced over stay end.
2	$\frac{13}{32}$ ”	” ” ”	495	” ” ”
3	$\frac{1}{2}$ ”	” ” ”	740	” ” ”
4	$\frac{9}{32}$ ”	Stays screwed through plate and fitted with nuts on the out side.	980	Plate cracked.
5	$\frac{13}{32}$ ”	” ” ”	1,200	Stays broke.
7	$\frac{13}{32}$ ”	” ” ”	1,200	Plate forced over nuts.
8	$\frac{15}{32}$ ”	” ” ”	1,550	” ”
6	$\frac{1}{2}$ ”	” ” ”	1,300	Stays broke.
9	$\frac{1}{2}$ ”	” ” ”	2,000	Plate forced over nuts.

The great advantage derived from fitting nuts to the stays is clearly shown, the bursting pressures of the $\frac{9}{32}$, $\frac{13}{32}$, and $\frac{1}{2}$ inch boxes with riveted stays being 350 lbs., 495 lbs., and 740 lbs. per square inch respectively, and of the boxes with nutted stays of the same size 980 lbs., 1,200 lbs., and 1,300 lbs. per square inch respectively, the latter exceeding the former very largely. The excess with the nutted stays is still larger with the $\frac{13}{32}$ and $\frac{1}{2}$ inch boxes, in which the stays were increased to 2 inches diameter. These stays, as well as the $1\frac{1}{2}$-inch stays in the $\frac{9}{32}$-inch box, are much larger than would be adopted in practice with the thickness of plate, and were only fitted in these cases to ensure the plate bursting before the stays broke. The nuts also in each case were made thicker in order to prevent the threads from stripping; due consideration must therefore be given to these facts when considering the bursting pressures.

The inferiority of the boxes fitted with riveted stays as compared with those in which the stays were screwed into the plates and fitted with nuts is very clearly shown by the curves of permanents sets, plate 9. In those for the former boxes it is seen that no permanent sets occur until a considerable pressure has been applied, but that they afterwards increase at a rather rapid rate over a short range of pressures, the curves then diverging suddenly from the perpendicular lines as the heads of the stays gave way. With the boxes in which the stays are screwed through the plate and fitted with nuts, not only are the bursting pressures much higher, but the boxes are not so subject to sudden failure, for at no time do the curves so rapidly diverge from the perpendicular lines as they are found to do with the former boxes. The greater regularity of the permanent sets during the whole period of the experiments is very marked as compared with those obtained from the boxes with riveted stays.

In deciding the working pressure suitable for the flat surfaces of boilers similiar to the boxes which have been tested, other considerations than the mere bursting pressures must be taken into account. The $\frac{9}{32}$-inch box with riveted stays gave way at 350 lbs. per square inch. The bulges were not recorded at this pressure, but at 300lbs. when the heads of four stays were cracked the mean bulge was 0·35 inch. It is clear that when during the test of the $\frac{9}{32}$-inch box with nutted stays an equal bulge occurred, the plate must have been just clearing the threads of the stays, and consequently liable to spring back from the nuts on the removal of the pressure. A boiler even if tested considerably below the pressure required to cause the above bulge would be overstrained, and liable to leakage at the stay holes. Unless a sufficiently high factor of safety is adopted in order to obviate overstraining, the working pressure for the combustion chamber of a boiler similarly constructed should not be decided upon entirely with reference to the bursting pressure, but the pressure at which the above bulge took place, viz., about 400 lbs. per square inch, should be considered. Again in the $\frac{13}{32}$-inch box with riveted stays the mean bulge recorded just before the box burst was 0·26 inch. In the two boxes of the same thickness with stays fitted with nuts, this amount of bulge was recorded at a pressure between 500 and 550 lbs. Both the $\frac{13}{32}$-inch boxes with nutted stays burst at a pressure of 1,200 lbs. per square inch, but as between 500 and 550 lbs. the extension in the stay holes was sufficient to free the plate from the stays, the same argument applies as in the case of the $\frac{9}{32}$-inch box. A consideration of the bulges in the case of the $\frac{1}{2}$-inch boxes will show, in a similar manner, that the working pressure for a combustion chamber similarly constructed to the boxes fitted with nutted stays, should be decided upon with reference to a pressure of about 825 lbs. rather than 2,000 lbs. per square inch, at which the plate of the $\frac{1}{2}$-inch box was forced over a nut.

During the experiments with the three last boxes, little or no leakage occurred round the stays whilst the pressure was on, as the circular shape of the bases of the nuts permitted the plate when bulging to accommodate itself to them, and make a watertight joint. Had the nuts where fitting against the plates been hexagonal, as is usually the case, this would not have occurred, as considerable leakage would have taken place and prevented the application of the high pressures recorded.

Attention has already been drawn to the fact of the high pressures recorded with the three last boxes, only been obtainable owing to the stays and nuts being much larger than would be fitted in practice. Although for the above reasons the working pressure is necessarily kept within much narrower bounds than might at first be thought necessary, the ductility and strength of the steel are most valuable, as they endow the steel combustion chamber of a boiler when fitted with nutted stays, with a very great safeguard against explosion in the event of the pressure applied having accidently been allowed to become too high.

The next experiment was made to ascertain the resistance to bursting of the flat ends of boilers in the steam space, when made of steel plate, and supported in the usual way by stays passing through the plate and fastened by nuts on each side. A box was constructed at the Glasgow Locomotive Works of $\frac{9}{16}$-inch steel plate supported by stays spaced 14 inches by 15½ inches, and fastened as above. The stays were 2¼ inches diameter over the thread, and screwed eleven threads to the inch; the nuts outside the plate were 2½ inches thick, and those inside 1½ inches. Sketches of the box and of the plates after the test are given in Plate 7.

The two sides of the box were marked O and P respectively, and the following bulges and sets were obtained during the test by hydraulic pressure.

EXPERIMENTAL BOX NO. 10. *Side O.*

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{9}{16}$-inch Steel Plate, supported by Stays passing through the Plate and fastened by Nuts on each side. Stays spaced 14 inches × 15½ inches.

Pressure per Square Inch.	Bulge.						Permanent Set.						Remarks.
	Point B.	Point E.	Point H.	Point A.	Point D.	Point G.	Point B.	Point E.	Point H.	Point A.	Point D.	Point G.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
25	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
50	·02	·01	·005	·02	·025	·005	”	”	”	”	”	”	
75	·04	·02	·02	·035	·035	·03	”	”	”	”	”	”	
100	·06	·04	·05	·06	·05	·04	”	”	”	”	”	”	
125	·10	·06	·06	·09	·07	·05	”	”	”	”	”	”	
150	·12	·09	·09	·10	·10	·07	”	”	·01	”	”	”	
175	·15	·10	·10	·13	·13	·13	·03	·03	·03	·01	·03	·02	
200	·22	·15	·15	·15	·16	·17	·06	·05	·05	·03	·06	·06	
225	·34	·20	·20	·20	·22	·21	·10	·10	·10	·08	·10	·09	
250	·56	·30	·29	·30	·30	·30	·23	·19	·18	·15	·19	·16	
275	·72	·52	·50	·50	·49	·46	·45	·40	·37	·39	·39	·33	
300	·83	·65	·64	·66	·62	·60	·60	·55	·53	·55	·53	·48	
325	·94	·75	·75	·78	·72	·71	·71	·65	·62	·65	·63	·60	
350	1·06	·83	·85	·90	·85	·83	·82	·75	·75	·78	·75	·72	
375	1·16	·93	·97	1·05	·95	·96	·96	·85	·86	·97	·88	·86	
400	1·25	1·0	1·06	1·12	1·04	1·06	1·05	·93	·97	1·01	·98	·95	
425	1·35	1·09	1·17	1·23	1·13	1·16	1·14	1·0	1·05	1·11	1·06	1·05	
450	1·44	1·17	1·27	1·33	1·23	1·25	1·24	1·07	1·14	1·23	1·15	1·15	
475	1·51	1·24	1·35	1·41	1·31	1·35	1·34	1·15	1·22	1·31	1·24	1·25	
500	1·60	1·31	1·42	1·49	1·40	1·43	1·42	1·22	1·30	1·40	1·34	1·35	
525	1·70	1·39	1·50	1·57	1·47	1·50	1·50	1·30	1·40	1·49	1·40	1·44	
550	1·76	1·47	1·58	1·65	1·55	1·60	1·58	1·38	1·47	1·56	1·48	1·51	
575	1·81	1·58	1·69	1·75	1·63	1·66	1·68	1·49	1·57	1·65	1·58	1·60	
600	1·85	1·63	1·75	1·82	1·72	1·75	1·76	1·55	1·65	1·74	1·66	1·70	
625	1·91	1·69	1·80	1·87	1·77	1·80	1·82	1·61	1·70	1·80	1·73	1·74	
650	1·99	1·78	1·88	1·95	1·87	1·86	1·90	1·69	1·78	1·88	1·80	1·80	
675	2·07	1·86	1·96	2·01	1·95	1·95	1·93	1·78	1·86	1·95	1·89	1·89	At 740 lbs. the plate at a stay-hole cracked, as shown in fig. 10, plate 7.
700	2·17	1·97	2·05	2·10	2·03	2·03	2·07	1·88	1·95	2·02	1·98	1·96	
740	2·33	2·15	2·18	2·20	2·17	2·13	2·21	2·03	2·06	2·10	2·03	2·03	

EXPERIMENTAL BOX No. 10. *Side P.*

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{9}{16}$-inch Steel Plate, supported by Stays passing through the Plate and fastened by Nuts on each side. Stays spaced 14 inches × 15½ inches.

Pressure in lbs. per Sq. In.	Bulge.						Permanent Set.						Remarks.
	Point B.	Point E.	Point H.	Point A.	Point D.	Point G.	Point B.	Point E.	Point H.	Point A.	Point D.	Point G.	
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
25	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
50	·01	·01	·01	·01	·01	·01	"	"	"	"	"	"	
75	·02	·025	·02	·025	·03	·02	"	"	"	"	"	"	
100	·04	·04	·03	·04	·05	·03	"	"	"	"	"	"	
125	·06	·05	·05	·06	·07	·05	"	"	"	"	"	"	
150	·08	·07	·07	·07	·10	·09	"	"	"	"	"	"	
175	·10	·09	·09	·13	·12	·10	·02	·02	·02	·02	·02	·02	
200	·14	·12	·12	·16	·15	·13	·05	·04	·05	·05	·04	·05	
225	·20	·17	·17	·20	·20	·19	·09	·08	·09	·08	·07	·08	
250	·29	·26	·25	·27	·29	·27	·17	·15	·15	·14	·14	·15	
275	·48	·46	·46	·44	·45	·43	·37	·36	·37	·30	·31	·31	
300	·62	·59	·63	·56	·60	·56	·51	·50	·53	·45	·46	·47	
325	·71	·67	·72	·66	·69	·69	·60	·57	·62	·54	·54	·56	
350	·80	·74	·82	·77	·78	·79	·70	·66	·72	·65	·65	·69	
375	·90	·83	·93	·87	·87	·90	·79	·75	·83	·79	·76	·80	
400	·98	·89	1·00	·96	·96	1·00	·87	·80	·91	·86	·84	·89	
425	1·04	·94	1·08	1·04	1·03	1·07	·94	·86	·98	·95	·91	·97	
450	1·12	1·01	1·17	1·13	1·10	1·16	1·01	·91	1·05	1·03	·99	1·06	
475	1·20	1·08	1·24	1·20	1·17	1·24	1·09	·97	1·15	1·12	1·06	1·15	
500	1·28	1·13	1·30	1·28	1·23	1·31	1·16	1·05	1·21	1·19	1·14	1·22	
525	1·35	1·21	1·39	1·35	1·31	1·39	1·24	1·12	1·29	1·27	1·21	1·31	
550	1·43	1·27	1·45	1·43	1·39	1·46	1·30	1·20	1·37	1·34	1·30	1·38	
575	1·52	1·31	1·50	1·50	1·46	1·52	1·39	1·25	1·43	1·43	1·39	1·45	
600	1·59	1·45	1·61	1·58	1·55	1·61	1·47	1·37	1·52	1·50	1·46	1·54	At 740 lbs., plate at a stayhole in side O cracked, as shown in fig. 10, plate 7.
625	1·63	1·49	1·67	1·64	1·60	1·66	1·53	1·41	1·57	1·56	1·51	1·59	
650	1·71	1·59	1·75	1·72	1·70	1·75	1·60	1·50	1·65	1·64	1·59	1·67	
675	1·80	1·68	1·84	1·80	1·78	1·83	1·70	1·59	1·74	1·72	1·70	1·76	
700	1·88	1·78	1·93	1·89	1·88	1·90	1·78	1·70	1·83	1·80	1·80	1·85	
740	1·92	1·88	2·02	1·96	1·98	2·01	1·85	1·81	1·93	1·86	1·89	1·92	

A further experiment was made in order to ascertain the additional strength afforded to the end plates of boilers by riveting to them thick washers at the stay holes, in the way sometimes adopted. A box was made at the Glasgow Locomotive Works of $\frac{9}{16}$-inch steel plate, with the plate in way of the stays strengthened by washers 9 inches diameter and ½ inch thick, riveted on by eight ¾-inch rivets. The stays and nuts were the same size as in the previous box, the stays being spaced 14 inches by 15 inches. Sketches of the box and of the plates after the experiments are given in Plate 8.

The results of testing by hydraulic pressure are as follows:—

EXPERIMENTAL BOX No. 11. *Side X.*

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{9}{16}$-inch Steel Plate, strengthened in way of the Stays by Washers 9 inches diameter and ½ inch thick riveted on. Stays spaced 14 inches × 15 inches.

Pressure per Sq. In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
50	Not perceptible.			Nil	Nil	Nil	
100	Not taken	·02	·02	„	„	„	
150	·03	·03	·03	„	„	„	
200	·05	·05	·05	„	„	„	
250	·07	·07	·07	„	„	„	
300	·11	·11	·11	·03	·03	·03	
350	·16	·16	·18	·06	·07	·06	
400	·32	·29	·33	·16	·16	·18	
450	·57	·54	·57	·44	·43	·44	
500	·83	·77	·82	·69	·65	·68	
550	1·14	·95	1·06	·91	·85	·91	
600	1·27	1·13	1·26	1·14	1·03	1·11	
650	1·44	1·29	1·43	1·33	1·18	1·30	
700	1·62	1·45	1·62	1·50	1·35	1·47	860 lbs. The threads of a nut stripped at the opposite side of box.
860	Not taken.	Not taken.	Not taken.	1·90	1·89	1·97	

EXPERIMENTAL BOX No. 11. *Side V.*

RESULTS of TESTING by HYDRAULIC PRESSURE a Box made of $\frac{9}{16}$-inch Steel Plate strengthened in way of the Stays by Washers 9 inches diameter and $\frac{1}{2}$ inch thick riveted on. Stays spaced 14 inches × 15 inches.

Pressure per Sq. In.	Bulge.			Permanent Set.			Remarks.
	Point B.	Point E.	Point H.	Point B.	Point E.	Point H.	
Lbs.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	
50	Nil	Nil	Nil	Nil	Nil	Nil	
100	·02	·02	·02	”	”	”	
150	·03	·03	·03	”	”	”	
200	·05	·05	·07	”	”	”	
250	·07	·09	·09	·01	·01	·01	
300	·11	·13	·13	·03	·03	·03	
350	·19	·18	·21	·07	·07	·09	
400	·39	·33	·40	·24	·21	·26	
450	·56	·55	·63	·48	·44	·50	
500	·78	·67	·76	·67	·59	·69	
550	·97	·85	1·00	·85	·74	·87	
600	1·13	1·00	1·17	·98	·87	1·04	
650	1·28	1·12	1·33	1·15	1·00	1·19	
700	1·44	1·27	1·50	1·30	1·14	1·34	
860	Not taken.	Not taken.	Not taken.	1·70	1·71	1·89	860 lbs.—At this pressure the threads of the nut of one of the centre stays stripped.

The system adopted for recording the bulges and permanent sets was the same as that previously described. Upon the box No. 10, with the stays fastened by nuts on each side, being tested, a slight permanent set occurred at 150 lbs. per square inch. Both bulges and permanent sets increased at a comparatively uniform rate up to about 250 lbs. per square inch, when a considerable increase in both took place, that of the permanent sets being shown very clearly by the curve in Plate 9. The box ultimately gave way at 740 lbs. per square inch by a crack in the plate at a stay hole. On the box No. 11, with the plate strengthened in way of the stays by large riveted washers, a slight permanent set was recorded on one side at 250 lbs. per square inch. The bulges increased gradually at a comparatively uniform and slightly increasing rate up to 350 lbs. Between this pressure and 400 lbs. a large increase occurred in both bulges and permanent sets, that of the latter being shown in the curve of sets, Plate 9. The box failed at 860 lbs. per square inch by the stripping of the thread of a nut of one of the centre stays.

The pressures at which the two boxes burst are thus 740 lbs. and 860 lbs. per square inch. Had the box with the large riveted washers not failed by the stripping of the nut, it is probable that a higher pressure would have been obtained; consequently the above figures do not, as regards the plate, correctly represent the real difference between the bursting pressures of the two boxes. If the pressures after which the permanent sets were observed to increase at a rapidly increasing rate, say 250 lbs. and 350 lbs. per square inch, be taken to represent the relative strength of the two systems of construction, it would appear that by the riveting on of the large washers the bursting pressure of the end of a boiler is increased about 40 per cent.

Comparing the bulges and permanent sets recorded with the boxes Nos. 10 and 11, it is seen that the differences are much the greatest at about 350 lbs. per square inch, but they become much less as the pressures increase. This would appear to show that No. 11 box, with the plate strengthened by the riveted washers, was failing quickly when the nut stripped, and that the allowance, 40 per cent., which we have assumed as the probable extent which the bursting pressure of the plate of No. 11 box exceeded that of No. 10, should be considered as a liberal estimate. When considering the increase of strength obtained by the riveting on of large washers it should not be forgotten that in No. 11 box the washers, compared with the plate, were proportionally thicker than are usually employed in such cases, and probably afforded a somewhat greater amount of strength than is usually given by them.

Comparing the curves of permanent sets, Plate 9, obtained from the boxes Nos. 10 and 11, it is seen that they are very similar in character, except that the sets are less in amount in the latter, in which large washers are fitted, than in the former. Comparing the curves with those obtained from the boxes with stays screwed into the plates and fitted with nuts, the former appear to diverge more rapidly than the latter from the perpendicular line; this, however, is due to the increase in the sets arising from the area between the stays in one case being above three times that in the other.

In the body of this report attention has been drawn to the desirableness of further experiments being carried out to ascertain (1) the loss of strength which occurs in lap riveted joints constructed of steel plates when the holes are punched, and (2) the effect of temperatures up to about 1,000° Fahrenheit upon the tensile strength and ductility of steel plate. It is desired, in conclusion, to give the fullest prominence to the advisableness of further experiments being made with reference to the above points.

The value to be attributed to steel plates when welded also urgently requires experimental investigation. Whilst some manufacturers assert their ability to weld steel plates, convincing proof is constantly afforded that others are unable to do so. Even in those establishments where the operation is considered to be properly performed, it is only entrusted to certain workmen, as other smiths equally good for general work cannot be depended upon to perform it with success.

The system adopted is found to differ at different works, but success appears to depend most upon the skill and experience of the workmen, and upon the care taken to avoid the injurious effects arising from the strains set up in the steel by local heating. The influence which these strains exert when the length of weld is considerable is very great, cases not unfrequently occurring in which the weld is found to give way when nearly completed. There can be no doubt that all welded plates or furnaces in which welded seams occur should be properly annealed afterwards.

An experiment was recently made to ascertain the value of an apparently perfect weld in a furnace which had been subsequently annealed, and the results showed that the weld was by no means so good as could have been obtained with iron. It is highly important that further experiments should be made in connexion with this subject.

One other remark should be made in conclusion. The observations made herein regarding mild steel are intended only to apply to steel manufactured by the Steel Company of Scotland, which is of the same quality as that of which the tests are attached. Proofs are not unfrequently given that with the increasing introduction of steel in ship building and boiler making, considerable variability occasionally occurs in its tensile strength and ductility. One great obstacle to the greater, or even continued use of steel for the above purposes may, it is feared, be found in the gradual reduction in its ductility, arising from the effects of competition between steel manufacturers.

THOMAS W. TRAILL.
THOMAS J. RICHARDS. PETER SAMSON.

The Assistant Secretary,
Marine Department.

APPENDIX.

PARTICULARS OF BENDING TESTS MADE AT THE WORKS OF THE STEEL COMPANY OF SCOTLAND AT NEWTON.

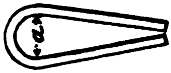
IN the following bending tests those plates noted as "tempered" were heated to a cherry red and cooled suddenly in water.

Fig. 1, Plate 1, shows the apparatus used for bending the strips marked 1, 2, 3, 7, 8, 9, 13, 14, 15.

Fig. 2 represents the apparatus adopted for bending the other specimens.

After the specimens were bent as far as the apparatus would allow, they were further bent and finally closed under the steam hammer.

In the following bending tests the specimens Nos. 1 to 22 were cut off the same steel plate (boiler plate), and were all 12 in. × 2 in. × ·96 in. Plate branded Steel Co., Scot., Ld.

In the following remarks a is the distance measured on the specimen thus , except where otherwise stated.

7. Untempered. Planed out of plate; corners left sharp. Bent without injury. $a = 1\frac{1}{8}$ in.

8. Untempered. Same remarks as for No. 7. Bent without injury. $a = 1\frac{1}{4}$ in.

9. Untempered. Same remarks as for No. 7. $a = 1\frac{1}{4}$ in.

10. Tempered; planed out of plate; corners left sharp. Bent without injury. $a = 1\frac{3}{8}$ in.

11. Same remarks as for No. 10. $a = 1\frac{3}{8}$ in.

12. Same remarks as for No. 10. $a = 1\frac{1}{2}$ in.

1. Untempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. No sign of fracture.

2. Untempered. Same remarks as for No. 1. Twisted $\frac{3}{4}$ in. when finished.

3. Untempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. Bent almost close without injury.

4. Tempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. No sign of fracture. $a = 1\frac{5}{16}$ in.

5. Tempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. No sign of fracture. $a = 1\frac{1}{4}$ in.

6. Tempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards; began to crack when legs were parallel $1\frac{1}{4}$ in. apart. Broke when being marked.

13. Untempered. Sheared off the plate; compressed corners on opposite sides of test piece. Began to show slight fracture when bent through angle 135°. When bent 150° the fracture slightly increased. Broke with an accidental sudden blow when legs were parallel $1\frac{3}{8}$ in. apart.

14. Untempered. Sheared off plate; compressed corners on opposite sides of test piece. Began to show fracture at one edge when legs were parallel $1\frac{3}{8}$ in. apart. Ends closed without much further injury. $a = 1\frac{5}{16}$ in.

15. Untempered. Sheared off plate; compressed corners on opposite sides of test piece. Received accidentally a heavy blow, and broke after being bent through angle 105°. Radius of curvature inside, 1 in.

16. Tempered. Sheared off plate; compressed corners on opposite sides of test piece. Bent without fracture. $a = 1\frac{3}{8}$ in.

17. Tempered. Same remarks as for No. 16. $a = 1\frac{9}{16}$ in.

18. Tempered. Same remarks as for No. 16. $a = 1\frac{7}{16}$ in.

19. Untempered. Sheared off plate; compressed corners on same side of test piece. Bent with compressed corners inwards. After being bent through an angle of 160°, edge began to crack slightly when $a = 1\frac{3}{4}$ in.

20. Untempered. Sheared off plate; compressed corners on same side of test piece. Bent with compressed corners inwards After being bent through an angle of 150°, edge began to crack slightly.

21. Untempered. Sheared off plate; compressed corners on same side of test piece. Bent with compressed corners outwards. Began to crack slightly after being bent through an angle of 160°. Bent to $1\frac{13}{16}$ in. parallel, with little increase in the fracture. $a = 1\frac{13}{16}$ in.

22. Untempered. Sheared off plate; compressed corners on the same side of test pieee. Bent with the compressed corners outwards. $a = 1\frac{7}{8}$ in.

In the following bending tests the specimens Nos. 23 to 44 were cut off the same steel plate (boiler plate), and were all 12 in. × 2 in. × ·71 in. Plate branded Steel Co., Scot., Ld.

29. Untempered. Planed out of plate; corners left sharp. Bent without injury. $a = 1\frac{5}{16}$ in.

30. Untempered. Same remark as for No. 29. Slight twist. $a = 1\frac{1}{4}$ in.

31. Untempered. Same remarks as for No. 29. Slight twist. $a = 1\frac{5}{16}$ in.

32. Tempered. Planed out of plate; corners left sharp. Bent without injury. Slight twist. $a = 1\frac{3}{8}$ in.

33. Tempered. Same remarks as for No. 32. $a = 1\frac{3}{8}$ in.

34. Tempered. Same remarks as for No. 32. $a = 1\frac{1}{8}$ in.

23. Untempered. Planed out of plate; two corners rounded. Bent double with rounded corners outwards.

24. Untempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards; closed uninjured.

25. Untempered. Planed out of plate; two corners rounded. Bent with rounded corners inwards. Bent close without injury.

26. Tempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. Cracked when almost closed.

27. Tempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards, without injury. $a = 1\frac{3}{8}$ in.

28. Tempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. Slight crack when $a = 1\frac{1}{2}$ in.

35. Untempered. Sheared off plate; compressed corners on opposite sides of test piece. When bent through angle of 90° slight crack at bottom sheared corner, which gradually increased till piece closed. $a = 1\frac{5}{16}$ in.

36. Untempered. Sheared off plate; compressed corners on opposite sides of test piece. Cracking slightly after being being bent through an angle of about 160°. Inside radius about $\frac{7}{8}$ in.

37. Untempered. Same description as No. 35. Bottom sheared corner began to crack slightly after being bent through an angle of about 135°. Bent parallel with legs $1\frac{3}{4}$ in. apart.

38. Tempered. Sheared off plate; compressed corners on opposite sides of test piece. Broke when just closing. $a = 1\frac{5}{8}$ in.

39. Tempered. Same description as No. 38. Closed without fracture. $a = 1\frac{7}{16}$ in.

40. Tempered. Same description as No. 38. Bottom sheared corner began to crack slightly after being bent through 135°. Broke with sudden blow when inside radius of bend was about $1\frac{1}{8}$ in.

41. Untempered. Sheared off plate; compressed corners on the same side of test piece. Bent with compressed corners inwards. Plate began to crack slightly just before being parallel with legs $1\frac{9}{16}$ in. apart.

42. Untempered. Same description as No. 41. Bent with compressed corners inwards. Broke when legs were parallel 2 inches apart.

43. Untempered. Sheared off plate; compressed corners on the same side of test piece. Bent with compressed corners outwards without fracture. $a = 1\frac{3}{8}$ in.

44. Untempered. Same as No. 43. Bent without fracture. Slight twist. $a = 1\frac{3}{8}$ in.

In the following bending tests the specimens Nos. 45 to 66 were cut off the same steel plate (ship plate), and were all 12 in. × 2 in. × ·505 in. Plate branded "Steel Co., Scot., Ld."

51. Untempered. Planed out of plate. Edges left sharp. Closed without fracture. $a = 1\frac{3}{16}$ in.

52. Untempered. Same description as No. 51. Closed without fracture. $a = 1\frac{1}{8}$ in.

53. Untempered. Same description as No. 51. Closed without fracture. $a = 1\frac{1}{8}$ in.

54. Tempered. Planed out of plate. Edges left sharp. Cracked a little at one edge when just closing. $a = 1\frac{1}{4}$ in.

55. Tempered. Same description as No. 54. Bent without fracture. $a = \frac{7}{8}$ in.

56. Tempered. Same description as No. 54. Closed without fracture. $a = 1$ in.

45. Untempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. Closed without fracture. Bent double close.

46. Untempered. Planed out of plate; two corners rounded. Bent with rounded corners inwards. Bent double close without injury, but twisted slightly.

47. Untempered. Same as No. 46. Bent double close without injury, but twisted slightly.

48. Tempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. Uninjured $a = \frac{13}{16}$ in.

49. Tempered. Same description as No. 48, but bent with rounded corners inwards. Began to crack slightly when ends closed and $a = 1\frac{3}{8}$ in.

50. Tempered. Same description as No. 49. Bent with rounded corners inwards. $a = \frac{15}{16}$ in.

57. Untempered. Sheared off plate; compressed corners on opposite sides of test piece. Began to crack slightly at bottom of sheared edge when legs were parallel $1\frac{1}{8}$ inches apart.

58. Untempered. Same description as No. 57. Began to crack very slightly at bottom of sheared edge when $a = 1\frac{3}{8}$ in.

59. Untempered. Same description as No. 57. Began to crack slightly at bottom of sheared edge when legs were parallel $1\frac{1}{2}$ inches apart.

60. Tempered. Sheared off plate; compressed corners on opposite sides of test piece. Cracked slightly at bottom of sheared edge when just closed. $a = 1\frac{1}{8}$ in.

61. Tempered. Same description as No. 60. Closed without fracture. $a = \frac{15}{16}$ in.

62. Tempered. Same description as No. 60. When closed showed the slightest sign of cracking at the bottom of sheared edge. $a = 1\frac{1}{8}$ in.

63. Untempered. Sheared off plate with compressed corners on the same side of test piece. Bent with compressed corners inwards. Bottom of sheared edge began to crack slightly when legs were parallel 2 inches apart.

64. Untempered. Same description as No. 63. Bent with compressed corners inwards. Outside edge began to crack slightly when legs were parallel 2 inches apart.

65. Untempered. Same description as No. 63; but bent with compressed corners outwards. Bent without fracture. $a = 1$ in.

66. Untempered. Same description as No 65. Began to crack slightly when $a = 1\frac{1}{4}$ in.

In the following bending tests the specimens Nos. 67 to 88 were cut off the same steel plate (ship plate), and were all 12 in. × 2 in. × ·25 in. Plate branded “ Steel Co. Scot., Ld.”

73. Untempered. Planed out of plate; corners left sharp. Bent without fracture. $a = \frac{5}{16}$ in.

74. Untempered. Same description as No. 73. Bent without fracture. $a = \frac{1}{2}$ in.

75. Untempered. Same description as No. 73. A very slight crack at one corner when $a = \frac{1}{2}$ in.

76. Tempered. Planed out of plate; corners left sharp. Slight crack at one corner when $a = \frac{1}{2}$ in.

77. Tempered. Same description as No. 76. Began to crack slightly at corners when legs were parallel $\frac{9}{16}$ in. apart.

78. Tempered. Same description as No. 76. Outside corners just beginning to crack when $a = \frac{7}{16}$ in.

67. Untempered. Planed out of plate; two corners rounded. Bent quite close without fracture, with rounded corners outwards.

68. Untempered. Same description as No. 67. No fracture.

69. Untempered. Same description as No. 67, but bent with the rounded corners inwards. No fracture.

70. Tempered. Planed out of plate; two corners rounded. Bent with rounded corners outwards. No fracture. $a = \frac{9}{16}$ in.

71. Tempered. Same description as No. 70. Bent with rounded corners outwards without fracture. $a = \frac{5}{8}$ in.

72. Tempered. Same description as No. 70. Bent with rounded corners inwards, without fracture. $a = \frac{1}{2}$ in.

85. Untempered. Sheared off plate with compressed corners on the same side of test piece. Bent with compressed corners inwards. Bottom sheared edge began to crack slightly after being bent through an angle of about 150°.

86. Untempered. Same description as No. 85. Bent with compressed corners inwards. Began to crack slightly when legs were $2\frac{1}{2}$ in. apart.

87. Untempered. Same description as No. 85, but bent with compressed corners outwards. Just beginning to crack slightly at one corner when closed at ends and $a = \frac{7}{16}$ in.

88. Untempered. Same description as No. 87. Corners just beginning to crack slightly when legs closed and $a = \frac{1}{2}$ in.

79. Tempered. Sheared off plate with compressed corners on opposite sides of test piece. Closed with slight crack at corner when $a = \frac{5}{8}$ in.

80. Tempered. Same description as No. 79. Closed without fracture. $a = \frac{15}{32}$ in.

81. Tempered. Same description as No. 79. Closed without fracture. $a = \frac{15}{32}$ in.

82. Tempered. Same description as No. 79. Closed without fracture. $a = \frac{7}{16}$ in.

83. Tempered. Same description as No. 79. Just beginning to crack slightly at one edge when $a = \frac{3}{8}$ in.

84. Tempered. Same description as No. 79. Closed without fracture. $a = \frac{9}{16}$ in.

The following specimens Nos. 89 to 95 were cut off a $\frac{5}{16}$ in. iron plate, branded *“ —— ” and were all 12 in. × 2 in. × $\frac{5}{16}$ in. They were bent in the same condition as received.

89. Sheared off plate with compressed corners on same side of test piece. Bent with compressed corners inwards. Broke when ends were $4\frac{1}{2}$ inches apart.

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* This is a Glasgow brand.

90. Same description as No. 89. Broke when ends were $5\frac{1}{4}$ in. apart.

91. Same description as No. 89, but bent with compressed corners outwards. Broke when ends were $4\frac{1}{2}$ inches apart.

92. Same description as No. 91. Broke when ends were 5 in. apart.

93. Planed out of plate. Broke when ends were $2\frac{5}{8}$ inches apart.

94. Planed out of plate. Broke when ends were $2\frac{5}{8}$ inches apart.

95. Planed out of plate. Broke when ends were $2\frac{5}{8}$ inches apart.

All the above specimens Nos. 89 to 95 gave way suddenly with scarcely any warning, and cracked right across at once.

The following specimens, Nos. 96 to 102, were cut off a $\frac{5}{8}$-inch iron plate branded in one place *"——Best Boiler", and in another place branded *"——Best Best Boiler". All 12 in. × 2 in. × $\frac{5}{8}$ in. and bent in the same condition as received.

96. Sheared off plate with compressed corners on same side of test piece. Bent with compressed corners inwards. Broke under swage.

97. Same description as No. 96. Cracked in several places when bent to angle of 90°.

98. Same description as No. 96, but bent with compressed corners outwards. Broke under swage.

99. Same description as No. 98. Broke when ends were $7\frac{5}{8}$in. apart.

100. Planed out of plate. Broke when ends were 8 in. apart.

101. Planed out of plate. Broke when ends were $7\frac{3}{4}$ inches apart.

102. Planed out of plate. Broke when ends were 8 inches apart.

All the above specimens, Nos. 96 to 102, gave way suddenly right across.

The following specimens, Nos. 103 to 109, were cut off an iron plate $\frac{15}{32}$ in. thick, branded †"——Best Best" and were all 12 in. × 2 in. × $\frac{15}{32}$ and bent in the same condition as received.

103. Sheared off plate with compressed corners on same side of test piece. Bent with compressed corners inwards. Cracked when ends were $7\frac{1}{4}$ in. apart.

104. Same description as No. 103. Cracked when ends were 6 in. apart.

105. Same description as No. 103, but bent with compressed corners outwards. Cracked when ends were $7\frac{1}{2}$ in. apart.

106. Same description as No. 105. Cracked when ends were $6\frac{1}{2}$ in. apart.

107. Planed out of plate. Cracked when ends were $5\frac{3}{4}$ in. apart.

108. Planed out of plate. Cracked when ends were 6 in. apart.

109. Planed out of plate. Cracked when ends were $6\frac{1}{4}$ in. apart.

All the above specimens, Nos. 103 to 109, gave way without warning.

The following specimens, Nos. 110 to 116, were cut off a $\frac{1}{4}$-inch iron plate, branded † "—— boiler." They were all 12 in. × 2 in. × $\frac{1}{4}$ in., and were bent in the same condition as received.

110. Sheared off plate with compressed corners on the same side of test piece. Bent with compressed corners inwards. Cracked when ends were $5\frac{1}{2}$ in. apart.

111. Same description as No. 110. Cracked when ends were $5\frac{1}{2}$ in. apart.

112. Same description as No. 110, but bent with compressed corners outwards. Cracked when legs were parallel $1\frac{7}{8}$ in. apart.

113. Same description as No. 112. Broke when ends were $6\frac{1}{2}$ in. apart.

114. Planed out of plate. Cracked when $a = 1\frac{5}{8}$ in.

115. Planed out of plate. Cracked when $a = 1\frac{1}{4}$ in.

116. Planed out of plate. Cracked when $a = 1\frac{3}{16}$ in.

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* This is a Glasgow brand.
† This is a Glasgow brand.

The following specimens Nos. 117 to 123, were cut off a $\frac{3}{8}$ in. iron plate branded * "——♛." They were all 12 in. × 2 in. × $\frac{3}{8}$ in., and were bent in the same condition as received.

117. Sheared off plate with the compressed corners on the same side of the test piece. Bent with compressed corners inwards. Bent through angle of 120°

118. Same description as No. 117. Cracked when ends were $8\frac{1}{4}$ in. apart.

119. Same description as No. 117, but bent with compressed corners outwards. Cracked when ends were $5\frac{1}{8}$ inches apart.

120. Same description as No. 119. Cracked when ends were $5\frac{3}{4}$ in. apart.

121. Planed out of plate. Cracked when ends were $4\frac{5}{8}$ in. apart.

122. Planed out of plate. Cracked when $a = 1\frac{3}{4}$ in.

123. Planed out of plate. Cracked when $a = 1\frac{9}{16}$ in.

The following specimens, Nos. 124 to 130, were cut off a $\frac{7}{16}$-in. iron plate, branded † "——." They were all 12 in. × 2 in. × $\frac{7}{16}$ in., and were bent in the same condition as received.

124. Sheared off plate with compressed corners on same side of test piece. Bent with compressed corners inwards. Broke under swage.

125. Same description as No. 124. Broke under swage.

126. Same description as No. 124, but bent with compressed corners outwards. Broke under swage.

127. Same description as No. 126. Cracked when ends were $7\frac{1}{4}$ in. apart.

128. Planed out of plate. Cracked when ends were $8\frac{3}{4}$ in. apart.

129. Planed out of plate. Cracked when ends were $7\frac{1}{4}$ in. apart.

130. Planed out of plate. Broke under swage.

The following specimens, Nos. 131, to 137, were cut off a $\frac{5}{16}$-in. iron plate, branded "Best" and "Best Boiler." They were all 12 in. × 2 in. × $\frac{5}{16}$ in., and were bent in the same condition as received.

131. Sheared off plate, with the compressed corners on the same side of test piece. Bent with compressed corners inwards. Cracked when ends were $9\frac{1}{2}$ in. apart.

132. Same description as No. 131. Cracked when ends were $1\frac{1}{16}$ in. apart.

133. Same description as No. 131, but bent with compressed corners outwards. Cracked when ends were $5\frac{5}{8}$ in. apart.

134. Same description as No. 133. Cracked when ends were $4\frac{5}{8}$ in. apart.

135. Planed out of plate. Cracked when ends were $5\frac{5}{8}$ in. apart.

136. Planed out of plate. Cracked when ends were $6\frac{1}{2}$ in. apart.

137. Planed out of plate. Cracked when ends were 6 in. apart.

EXPERIMENTS made to ascertain the EFFECTS of BENDING STEEL PLATE COLD, and when heated to the Temperature of Boiling Tallow.

The specimens were all bent in the apparatus in Fig. 2, Plate 1, and closed by the steam hammer.

In the following experiments, Nos. 160 to 165, the specimens were all 12 in. × 2 in. × ·25 in., and were planed out of steel plate branded "Steel Co. Scot. Ld."

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* This is a Cleveland brand

† This is a Glasgow brand

160. Bent cold. $a = \frac{1}{2}$ in. · No fracture.

161. Bent cold. $a = \frac{1}{2}$ in. No fracture.

162. Bent cold. $a = \frac{7}{16}$ in. No fracture.

163. Bent when heated to temperature of boiling tallow. Cracked suddenly when $a = 1\frac{3}{16}$ in.

164. Bent when heated to temperature of boiling tallow. Just beginning to crack when $a = 1\frac{7}{16}$ in.

165. Bent when heated to temperature of boiling tallow. Cracked when $a = \frac{13}{16}$ in.

The following specimens, No. 166 to 171, were planed out of steel plate branded "Steel Co. Scot. Ld.," and were all 12 in. × 2 in. × ·51 in.

166. Bent cold. $a = 1$ in. No fracture.

167. Bent cold. $a = 1$ in. No fracture.

168. Bent cold. $a = 1$ in. No fracture.

169. Bent when heated to temperature of boiling tallow. Just beginning to crack when $a = 1\frac{9}{16}$ in.

170. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{3}{16}$ in.

171. Bent when heated to temperature of boiling tallow. Just beginning to crack when $3\frac{1}{2}$ in. open at ends.

The following specimens, Nos. 172 to 177, were all 12 in. × 2 in. × ·25 in.

172. Bent cold. Great twist caused one edge to show slight sign of fracture when $a = \frac{1}{2}$ in.

173. Bent cold. Not fractured. $a = \frac{7}{16}$ in.

174. Bent cold. Edge cracking slightly when $a = \frac{1}{2}$ in.

175. Bent when heated to temperature of boiling tallow. Beginning to crack slightly when $a = 1\frac{3}{8}$ in.

176. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{3}{16}$ in.

177. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{3}{16}$ in.

The following specimens, Nos. 178 to 183, were all 12 in. × 2 in. × ·36 in.

178. Bent cold. Not fractured. $a = \frac{19}{32}$ in.

179. Bent cold. Not fractured. $a = \frac{1}{2}$ in.

180. Bent cold. Not fractured. $a = \frac{1}{2}$ in.

181. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{3}{8}$ in.

182. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{7}{16}$ in.

183. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{3}{16}$ in.

The following specimens, 184 to 189, were planed out of steel plate branded "Steel Co. Scot. Ld.," and were 12 in. × 2 in. × ·3 in.

184. Bent cold. Not fractured. $a = \frac{9}{16}$ in.

185. Bent cold. Not fractured. $a = \frac{9}{16}$ in.

186. Bent cold. Not fractured. $a = \frac{1}{2}$ in.

187. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{5}{16}$ in.

188. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{1}{4}$ in.

189. Bent when heated to temperature of boiling tallow. Cracked when $a = 1\frac{5}{16}$ in.

The following specimens, 190 to 195, were all 12 in. × 2 in. × ·75 in.

190. Bent cold. Cracking slightly at one edge when $a = 1\frac{3}{8}$ in.

191. Bent cold. Not fractured. $a = 1\frac{5}{8}$ in.

192. Bent cold. Not fractured. $a = 1\frac{7}{16}$ in.

193. Bent when heated to temperature of boiling tallow. Cracked.

194. Bent when heated to temperature of boiling tallow. Broken.

195. Bent when heated to the temperature of boiling tallow. Cracked when ends were 7 inches apart.

The following specimens, Nos. 196 to 201, were all planed out of steel plate, branded " Steel Co., Scot., L^{d} " and were all 12 in. × 2 in. × 1·01 in.

196. Bent cold much past the prescribed test, cracking at the edge slightly when $a = 1\frac{1}{8}$ in.

197. Bent when heated to temperature of boiling tallow. Broken.

198. Bent when heated to temperature of boiling tallow. Cracked.

199. Bent when heated to temperature of boiling tallow. Cracked when bent to an angle of about 90°.

200. Bent when heated to temperature of boiling tallow. Cracked when interior angle 60°.

201. Bent when heated to temperature of boiling tallow. Cracked when interior angle 85°.

The following bulging or dishing tests made at the Works of the Steel Company of Scotland were done under a steam hammer, and with apparatus shown in Fig. 3, Plate 1.

138. Steel ship-plate, $10\frac{1}{2}$ in. diameter and $\frac{7}{16}$ in. thick, branded "Steel Co. Scot. Ld." Dished to a depth of $3\frac{1}{4}$ in. uninjured.

140. Iron plate, $10\frac{1}{4}$ in. diameter, and $\frac{7}{16}$ in. thick branded *"————" When dished 1 in. there was an elliptical crack about $3\frac{3}{8}$ in. by $2\frac{3}{4}$ in. and the plate was completely destroyed when dished 2 inches.

141. Iron plate, $10\frac{1}{2}$ in. diameter, and $\frac{1}{2}$ in. thick branded †"——Best Best." When dished 1 inch there was a crack $\frac{1}{2}$ inch in length. Broke when dished $2\frac{1}{4}$ inches.

FOUR BENDING TESTS of Ships' Angles, two of Steel and two of Iron.

142. Steel Angle, 2 ft. 8 in. by $2\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × $\frac{5}{16}$ in., branded " Steel Co. Scot. L^{d}. " It was first flattened out under the steam hammer, then gripped between the hammer and the anvil and bent over with a sledge hammer with the ridge outside, and finally doubled over in the direction of its length with the ends parallel $\frac{3}{8}$ inch apart without fracture.

143. Steel angle, 2 ft. 6 in. × $3\frac{1}{4}$ in. × 3 in. × $\frac{5}{16}$ in., branded " Steel Co. Scot. L^{d}." Flattened out in same manner as No. 142. The middle portion for a length of 11 inches was then turned back on to the ridge, and finally cracked for a length of $5\frac{1}{2}$ inches after being well bent back.

144. Iron ships' angle, 2 ft. × $3\frac{1}{2}$ in. × $3\frac{1}{4}$ in. × $\frac{5}{16}$ in. It was attempted to flatten it under the steam hammer, but showed signs of cracking when it had opened about $\frac{1}{2}$ inch, and finally gave way suddenly along its whole length, the cracks being on opposite sides of the ridge. Angle branded "————."

145. Iron ships' angle. 2 ft. × 3 in. × 3 in. × $\frac{1}{2}$ in., branded "————". It was attempted to flatten it by the steam hammer but broke suddenly along its whole length at the beginning of the fillet. The pieces were then bent

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* This is a Glasgow brand.

† This is another Glasgow brand.

as in the manner described with No. 142. The half without the fillet was then bent until the ends were five inches apart, and was then badly cracked. The piece on which the fillet remained was then bent until it cracked right across, when $a = 1\frac{1}{2}$ inches.

EXPERIMENTS to ascertain the EFFECTS of DRIFTING upon STEEL PLATES and IRON PLATES.

The following experiments were carried out at the works of the Steel Company of Scotland in order to ascertain the effects of drifting holes in steel plates and in iron plates :—

The drifts used were as shown in Plate 3. In experiments Nos. 146 and 147, they were rough from the hammer, but in the succeeding experiments, they were turned, except where otherwise stated. Each punch was driven half-way through the plate and then driven from the other side.

The pieces of steel plates used in experiments Nos. 146 to 153 were all cut from the same plate, branded "Steel Co. Scot., L^{d}."

146. Steel plate 6½ in. × 6½ in. × ½ in. Hole in centre drilled ¾ in. and drifted out to 2¼ inches diameter, the burr only being cracked and the plate othewrise uninjured.

147. Steel plate 6½ in. × 6½ in. × ½ in. Hole drilled ¾ inch and drifted out to 2⅛ inches diameter. The burr cracked, but there was no fracture in the plate.

148. Steel plate 6½ in. × 6½ in. × ½ in. Holed drilled ¾ in. With the 5th drift the burred edge of hole cracked slightly, and the plate began to tear at the hole inside.

With the 6th drift the plate cracked in ¾ inch from one outside edge.

With the 7th drift, when 2¾ inches from being through, the plate gave way suddenly when the diameter of the hole was 2⅜ inches.

149. Steel plate 6½ in. × 6½ in. × ½ in. Hole bored ¾ in.

With the 5th drift the plate began to crack at outside edge.

With the 6th drift the plate gave way when one inch from being through, the diameter of the hole being 2¼ inches.

150. Steel plate 6½ in. × 6½ in. × ½ in. Hole punched ¾ inch.

With the 5th drift, when 2 inches from being through, the plate began to crack slightly at outside edge.

With the 6th drift, when 3¼ inches from being through, the plate cracked, the diameter of the hole being 2⅛ inches.

151. Steel plate 6½ in. × 6½ in. × ½ in. Hole punched ¾ inch.

With the 4th drift, when 1 inch from being through, the plate cracked at outside edge.

With the 6th drift the crack at edge extended $\frac{5}{16}$ inch.

With the 7th drift there were cracks on three sides, the diameter of the hole being 2½ inches.

152. Steel plate 6½ in. × 6½ in. × ½ in. Hole punched ¾ inch and drilled out to 1 inch.

With the 4th drift, when 3½ inches from being through, the plate cracked a little at two outside edges.

With the 6th drift, one of the cracks extended from the edge about half-way to the hole.

With the 7th drift, when 2 inches from being through, the crack extended to the hole, which had increased in diameter to 2⅜ inches.

153. Steel plate 6½ in. × 6½ in. × ½ in. Hole punched ¾ inch and drilled out to 1 inch.

With the 8th drift there was a slight crack at outside edge and at the hole, which had increased in diameter to 2¾ inches.

153A. Steel plate 10 in. × 10 in. × ½ in. Hole drilled ¾ inches.
With the 9th drift there was a very slight crack at one outside edge.
With the 10th drift the crack increased to ½ inch.
With the 11th drift the crack increased to 1⅛ inch.
With the 12th drift the crack increased to 1⅝ inch.
With the 13th drift the plate cracked right through, tearing up gradually to within one inch of the hole, and then giving way suddenly. The diameter of the hole was increased to 3½ inches.

153B. Steel plate 10 in. × 9¾ in. × ½ in. Hole punched ¾ inch.
With the 6th drift the burr at the hole slightly cracked.
With the 7th drift the plate began to crack.
With the 8th drift the crack increased to ¼ inch.
With the 9th drift the crack increased to ⅜ inch.
With the 10th drift the crack increased to 1½ inch.
With the 11th drift the plate cracked through, the hole being 3¼-inches diameter.

The drifts 11, 12, and 13 were common black drifts such as are used in the smithy.

The following drifting tests, Nos. 154 to 156, were made on pieces of ½-inch iron plate, branded * "—— Best Best."

154. Iron plate. 6½ in. × 6½ in. × ½ in. Hole bored ¾ inch diameter.
With the 2nd drift, when half way through, a slight crack began to show at the outside edge of the plate. When one inch from through, crack began at the hole, and extended into the plate about ½-inch. When ¾ inch from through, the plate cracked at the edge.
With the 3rd drift, when 4½ inches from through, the plate cracked across to the hole.

155. Iron plate 6½ in. × 6½ in. × ½ in. Hole punched ¾ in.
With the 2nd drift, when 2¼ inches from through, the plate cracked slightly at one edge. The crack extended right to the hole when the drift was ¾ inch from through. Hole increased in diameter to 1½ inch.

156. Iron plate 6½ in. × 6½ in. × ½ in. Hole punched ¾ inch and drilled to 1 inch.
With the 2nd drift, when 1¼ inch from through, the plate cracked suddenly from the edge to the hole.
The following drifting tests were made on pieces of a ⅝-inch iron plate, branded † "—— Best Boiler" and † "——Best Best Boiler."

157. Plate 6½ in. × 6½ in. × ⅝ in. Hole drilled ¾ inch.
With the 1st drift, when almost through, the plate cracked at outside edge ¾ inch.
With the 2nd drift the plate cracked across when the drift was 4⅜ inches from being through. Diameter of hole increased to 1¼ inch.

158. Plate 6½ in. × 6½ in. × ⅝ in. Hole punched ¾ inch.
With the 2nd drift, when 3¼ inches from through, the plate cracked at hole and at the edge. When the drift was 2½ inches from being through, the plate cracked right across. Hole increased in diameter to 1⅜ inch.
159. Plate 6½ in. × 6½ in. × ⅝ in. Hole punched ¾ inch, and drilled to 1 inch diameter.
With the 2nd drift, when 1½ inch from through, the plate cracked at hole and at edge. When 1¾ inch from being through, the plate cracked right across. Hole increased in diameter to 1½ inch.

THOMAS W. TRAILL.

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* This is a Glasgow braud.
† This is a Glasgow brand.

TABLE 1.

SUMMARY of the RESULTS of EXPERIMENTS to ascertain the ELASTIC and ULTIMATE
Company of Scotland. Nominal thicknesses

Lengthway.

Stamped.	Test No.	Thickness.	Stress.		Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Stress per square inch of Fractured Area.	Extension Set in Ten Inches.			Appearance of Fracture.
			Elastic per square inch.	Ultimate per square inch.				At 50,000 lbs. per sq. in.	At 60,000 lbs. per sq. in.	Ultimate.	
	L.	inch	lbs. tons.	lbs. tons.	per cent.	per cent.	lbs.	per cent.	per cent.	per cent.	
4	2970	·25	45,800=20·5	70,110=31·2	65·3	41·4	119,641	0·29	4·98	21·7	100 % Silky
	2971	·25	47,800=21·3	71,420=31·8	66·9	43·6	126,631	0·20	4·26	20·1	do.
4	2985	·24	45,900=20·5	70,180=31·2	65·4	51·6	145,200	0·30	4·62	20·0	do.
	2986	·24	47,900=21·3	71,640=31·9	66·8	52·3	150,162	0·18	4·26	21·6	do.
		Mean	**46,850=21·0**	**70,837=31·6**	**66·1**	**47·2**	**135,408**	**0·24**	**4·53**	**20·8**	
2	3000	·51	35,500=15·8	65,490=29·2	54·2	48·2	126,514	4·31	10·1	29·6	do.
	3001	·51	35,400=15·7	65,410=29·2	54·1	47·5	124,706	4·61	10·4	29·2	do.
	3015	·51	36,600=16·3	65,880=29·4	55·5	50·5	133,064	4·76	10·5	29·1	do.
	3016	·51	36,200=16·1	64,720=28·9	55·9	50·9	131,765	4·82	10·6	29·9	do.
		Mean	**35,922=16·0**	**65,375=29·2**	**54·9**	**49·2**	**129,012**	**4·62**	**10·4**	**29·4**	
9	3030	·78	35,400=15·7	65,055=29·0	54·4	48·4	126,069	4·81	10·7	29·8	do.
	3031	·76	35,200=15·6	63,860=28·5	55·1	47·8	122,869	5·19	11·9	29·6	do.
0	3045	·76	36,300=16·2	69,590=31·0	52·1	51·0	141,982	3·69	7·57	29·2	do.
	3046	·77	35,900=16·0	67,935=30·3	52·8	51·3	139,493	3·78	8·19	29·1	do.
		Mean	**35,700=15·9**	**66,610=29·7**	**53·6**	**49·6**	**132,603**	**4·36**	**9·25**	**29·4**	
7·8	3060	·98	31,800=14·2	61,925=27·7	51·3	38·0	99,813	6·01	14·2	27·7	do.
	3061	·96	32,900=14·7	62,760=28·0	52·4	43·9	111,988	5·17	12·6	29·9	do.
7·8	3075	·98	32,900=14·7	61,955=27·7	53·1	49·1	121,675	6·11	14·5	29·8	do.
	3076	·99	32,700=14·6	61,770=27·6	52·9	51·7	128,067	6·03	15·4	31·2	do.
		Mean	**32,575=14·6**	**62,102=27·7**	**52·4**	**45·7**	**115,386**	**5·83**	**14·2**	**29·6**	

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

Plates branded

TABLE 1.

ILE Strength of EIGHT STEEL PLATES, received direct from Messrs. The Steel
ter, half, three-quarters, and one inch.

Crossway.											
mped.	Test No.	Thickness.	Stress.		Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Stress per square inch of Fractured Area.	Extension Set in Ten Inches.			Appearance of Fracture.
			Elastic per square inch.	Ultimate per square inch.				At 50,000 lbs. per sq. in.	At 60,000 lbs. per sq. in.	Ultimate.	
	L.	inch.	lbs. tons.	lbs. tons.	per cent.	per cent.	lbs.	per cent.	per cent.	per cent.	
4	2973	·25	47,800=21·3	73,810=33·0	64·7	35·8	114,968	0·21	3·05	13·6	100 °/o Silky
	2974	·25	47,800=21·3	72,730=32·5	65·7	35·8	113,286	0·20	3·67	16·8	do.
4	2988	·24	47,900=21·4	72,910=32·6	65·6	44·1	130,585	0·19	3·39	18·0	do.
	2989	·24	49,700=22·2	76,920=34·3	64·6	44·1	137,767	0·11	1·38	20·4	do.
		Mean	**48,300=21·5**	**74,092=33·0**	**65·1**	**39·9**	**124,151**	**0·18**	**2·87**	**17·2**	
2	3003	·51	35,900=16·0	65,820=29·3	54·5	36·7	104,411	4·34	10·2	27·6	do.
	3004	·51	35,700=15·9	64,780=28·9	55·1	42·6	113,143	4·72	10·5	27·0	do.
2	3018	·51	36,400=16·2	65,670=29·2	55·4	35·0	101,490	4·85	10·5	25·3	do.
	3019	·51	36,800=16·3	65,980=29·4	55·7	35·8	103,220	4·59	10·1	27·9	do.
		Mean	**36,200=16·1**	**65,562=29·2**	**55·2**	**37·5**	**105,566**	**4·62**	**10·3**	**26·9**	
9	3033	·78	34,300=15·3	64,295=28·7	53·3	28·8	90,279	5·01	11·2	24·2	do.
	3034	·77	34,300=15·8	63,805=28·5	53·7	27·0	87,419	5·11	11·6	24·6	do.
0	3048	·76	35,700=15·9	68,125=30·4	52·4	39·7	112,922	3·92	8·16	27·0	do.
	3049	·77	36,100=16·1	67,965=30·3	53·1	47·1	128,424	3·57	7·60	28·2	do.
		Mean	**35,100=15·6**	**66,047=29·5**	**53·1**	**35·6**	**104,761**	**4·40**	**9·64**	**26·0**	
7·8	3063	·97	32,700=14·6	61,890=27·6	52·8	37·0	98,254	5·48	12·7	21·1	95 °/o do.
	3064	·99	33,100=14·7	62,670=28·0	52·8	35·0	96,338	4·04	11·1	22·9	95 °/o do.
7·8	3078	·98	32,700=14·6	61,720=27·5	52·9	38·0	99,564	5·52	14·2	26·2	100 °/o do.
	3079	1·00	32,500=14·5	61,290=27·3	53·0	41·1	104,146	5·69	15·1	27·6	100 °/o do.
		Mean	**32,750=14·6**	**61,892=27·6**	**52·9**	**37·8**	**99,825**	**5·18**	**13·3**	**24·4**	

(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 5th March, 1878.

TABLE 2.

RESULTS of EXPERIMENTS to ascertain the effects produced by

Two Steel Plates, received direct from

Nominal thickness,

Sketch of Plates with Holes.		
Test number and thickness -	L 2977 ¼ inch	L 2992 ¼-inch
Holes - - - - -	*Drilled.*	*Drilled.*
Plates, brand - - -	S.C. of S. L.G.S.	S.C. of S.L.G.S
Plates, width and thickness -	12·00 × ·25	12·00 × ·24
Plates, sectional area, gross -	3·00	2·88
Stress total - -	lbs. tons. 146,720 = 65·5	lbs. tons. 141,930 = 63·3
Stress per square inch of gross area at holes - - -	*48,907 = 21·8*	*49,281 = 22·0*
Stress per square inch of plates, solid - - - -	*70,765 = 31·6*	*70,910 = 31·7*
Ratio of holes to solid - -	*69·1*	*69·5*
Appearance of fracture - -	100 °/₀ Silky	100 °/₀ Silky
Holes, diameter and number -	·79 × 6 = 4·74	·79 × 6 = 4·74
Holes, elongated, inch - -	·26 + ·14 = ·40	·24 + ·13 = ·37
Holes, elongated, per cent. -	*25·3*	*23·4*
Width of plates, less holes, per centage - - - -	60·5	60·5

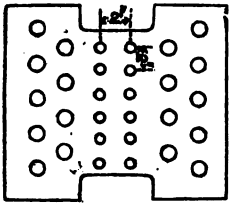
Thomas W. Traill, Esq.,
The Engineer, Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

TABLE 2.

DRILLED HOLES and by PUNCHED HOLES, under Pulling Stress.

Messrs. The Steel Company of Scotland.

quarter-inch.



L 2978 ¼-inch	L 2993 ¼-inch	L 2979 ¼-inch	L 2994 ¼-inch
Punched.	*Punched.*	*Punched and annealed.*	*Punched and annealed.*
S.C. of S. L.G.S.	S.C. of S. L.G.S.	S.C. of S. L.G.S.	S.C. of S. L.G.S.
12·00 × ·25	12·00 × ·24	12·00 × ·25	12·00 × ·24
3·00	2·88	3·00	2·88
lbs. tons. 129,870 = 58·0	lbs. tons. 124,710 = 55·7	lbs. tons. 138,320 = 61·7	lbs. tons. 128,270 = 57·2
43,290 = 19·3	*43,302 = 19·3*	*46,107 = 20·5*	*44,538 = 19·8*
70,765 = 31·6	*70,910 = 31·7*	*70,765 = 31·6*	*70,910 = 31·7*
61·1	*61·0*	*65·2*	*62·8*
100 °/₀ Silky	100 °/₀ Silky	100 °/₀ Silky	100 °/₀ Silky
·79 × 6 = 4·74	·79 × 6 = 4·74	·79 × 6 = 4·74	·79 × 6 = 4·74
·13 + ·06 = ·19	·13 + ·05 = ·18	·26 + ·15 = ·41	·29 + ·16 = ·45
12·0	*11.4*	*25·9*	*28·4*
60·5	60·5	60·5	60·5

(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 1st May 1878.

TABLE 3.

RESULTS of EXPERIMENTS to ascertain the EFFECTS produced by
Two Steel Plates, received direct from
Nominal thickness,

Sketch of Plates with Holes.		
Test number and thickness -	L 3007 ½-inch	L 3022 ½-inch
Holes - - - -	*Drilled.*	*Drilled.*
Plates, brand - - -	S.C. of S.L.G.S.	S.C. of S.L.G.S.
Plates, width and thickness	12·00 × ·51	12·00 × ·51
Plates, sectional area, gross -	6·12	6·12
Stress, total - - -	lbs. tons. 268,830 = 120·0	lbs. tons. 269,570 = 120·3
Stress per square inch of gross area at holes- - - -	*43,926 = 19·6*	*44,047 = 19·6*
Stress per square inch of plates, solid - - - -	*65,450 = 29·2*	*65,300 = 29·1*
Ratio of holes to solid - -	*67·1*	*67·4*
Appearance of fracture - -	100 °/₀ Silky	100 °/₀ Silky
Holes, diameter and number -	·79 × 6 = 4·74	·79 × 6 = 4·74
Holes, elongated, inch - -	·36 + ·24 = ·60	·35 + ·22 = ·57
Holes, elongated, per cent. -	*38·0*	*36·1*
Width of plates, less holes percentage - - -	60·5	60·5

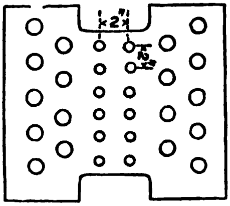
Thomas W. Traill, Esq.,
The Engineer, Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

TABLE 3.

DRILLED HOLES and by PUNCHED HOLES, under Pulling Stress.

Messrs. The Steel Company of Scotland.

half-inch.



L 3008 ½-inch	L 3023 ½-inch	L 3009 ½-inch	L 3024 ½-inch
Punched.	*Punched.*	*Punched and annealed.*	*Punched and annealed.*
S.C. of S.L.G.S.	S.C. of S.L.G.S.	S.C. of S.L.G.S.	S.C. of S.L.G.S.
12·00 × ·51	12·00 × ·51	12·00 × ·51	12·00 × ·51
6·12	6·12	6·12	6·12
lbs. tons. 227,780 = 101·7	lbs. tons. 229,320 = 102·3	lbs. tons. 251,880 = 112·4	lbs. tons. 259·610 = 115·9
37,219 = 16·6	*37,471 = 16·7*	*41,157 = 18·3*	*42,419 = 18·8*
65,450 = 29·2	*65,300 = 29·1*	*65,450 = 29·2*	*65,300 = 29·1*
56·9	*57·3*	*62·9*	*64·8*
95 °/o Silky 5 °/o Granular.	100 °/o Silky	100 °/o Silky	100 °/o Silky
·79 × 6 = 4·74	·79 × 6 = 4·74	·79 × 6 = 4·74	·79 × 6 = 4·74
·22 + ·07 = ·29	·23 + ·07 = ·30	·36 + ·19 = ·55	·37 + ·19 = ·56
18·3	*18·7*	*34·8*	*35·4*
60·5	60·5	60·5	60·5

(Signed) **DAVID KIRKALDY,**
99, Southwark Street,
London, S.E., 1st May 1878

TABLE 4.

RESULTS of EXPERIMENTS to ascertain the EFFECTS produced by Two Steel Plates received direct from

Nominal thickness,

Sketch of Plates with Holes.		
Test number and thickness -	L 3037 ¾-inch.	L 3052 ¾-inch.
Holes - - - -	*Drilled.*	*Drilled.*
Plates, brand - - -	S.C. of S.L.G.S.	S.C. of S.L.G.S.
Plates, width and thickness -	12·00 × ·77	12·00 × ·77
Plates, sectional area, gross -	9·24	9·24
Stress total - - -	lbs. tons. 387,750=173·1	lbs. tons. 428,320=191·2
Stress per square inch of gross area at holes - -	*41,965=18·7*	*46,354=20·6*
Stress per square inch of plates solid - - -	*64,457=28·7*	*68,761=30·7*
Ratio of holes to solid - -	*65·1*	*67·4*
Appearance of fracture - -	95°/₀ Silky 5°/₀ Granular	92°/₀ Silky 8°/₀ Granular
Holes, diameter and number -	·79 × 6=4·74	1·08 × 4=4·32
Holes, elongated, inch - -	·39 + ·25=·64	·48 + ·27=·75
Holes, elongated per cent. - -	*40·5*	*34·7*
Width of plates less holes per-centage - - -	60·5	64·0

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
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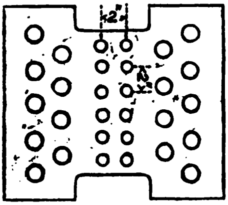
Table 4.

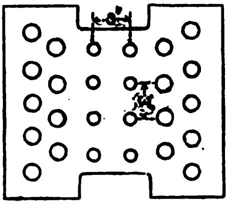
Drilled Holes and by **Punched Holes**, under Pulling Stress.
Messrs. The Steel Company of Scotland.

three-quarter-inch.

L 3037, 3038, 3039.



L 3052, 3053, 3054.



L 3038 ¾-inch	L 3053 ¾-inch	L 3039 ¾-inch	L 3054 ¾-inch.
Punched.	*Punched.*	*Punched and annealed*	*Punched and annealed.*
S.C. of S.L.G.S.	S.C. of S.L.G.S.	S.C. of S.L.G.S.	S.C. of S.L.G.S
12·00 × ·77	12·00 × ·77	12·00 × ·77	12·00 × ·77
9·24	9·24	9·24	9·24
lbs. tons. 301,350=134·5	lbs. tons. 350,810=156·6	lbs. tons. 363,080=162·1	lbs. tons. 412,240=184·0
32,613=14·6	*37,967=17·0*	*39,294=17·5*	*44,615=19·9*
64,457=28·7	*68,761=30·7*	*64,457=28·7*	*68,761=30·7*
50·6	*55·2*	*60·9*	*64·9*
30°/₀ Silky 70°/₀ Granular.	45°/₀ Silky 55°/₀ Granular.	100°/₀ Silky	100°/₀ Silky
·79 × 6=4·74	1·08 × 4=4·32	·79 × 6=4·74	1·08 × 4=4·32
·11 + ·06=·17	·19 + ·06=·25	·34 + ·22=·56	·39 + ·27=·66
10·7	*11·6*	*35·4*	*30·6*
60·5	64·0	60·5	64·0

(Signed) David Kirkaldy,
99, Southwark Street,
London, S.E., 3rd May 1878.

TABLE 5.

RESULTS of EXPERIMENTS to ascertain the EFFECTS produced by
Two Steel Plates received direct from
Nominal thickness,

Sketch of Plates with Holes.		
Test number and thickness	L 3067 1-inch	L 3082 1-inch
Holes	*Drilled.*	*Drilled.*
Plates, brand	S.C. of S.L.G.S.	S.C. of S.L.G.S.
Plates, width and thickness	12·00 × ·99	12·00 × ·98
Plates, sectional area, gross	11·88	11·76
Stress total	lbs. tons. 504,550=225·2	lbs. tons. 465,820=207·9
Stress per square inch of gross area at holes	*42,470=19·0*	*39,610=17·6*
Stress per square inch of plates solid	*62,342=27·8*	*61,862=27·6*
Ratio of holes to solid	*68·1*	*64·0*
Appearance of fracture	20% Silky 80% Granular.	93% Silky 7% Granular.
Holes, diameter and number	1·08 × 4=4·32	·79 × 6=4·74
Holes, elongated inch	·32 + ·24= ·56	·42 + ·23= ·65
Holes, elongated per cent.	*25·9*	*41·1*
Width of plates less holes percentage	64·0	60·5

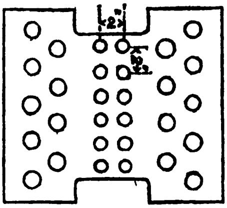
Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13 Downing Street, Westminster.

TABLE 5..

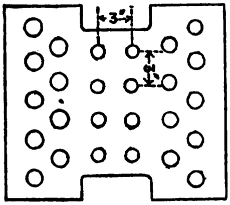
**DRILLED HOLES and by PUNCHED HOLES, under Pulling Stress.
Messrs. The Steel Company of Scotland.**

one inch.

L 3082.



L 3067, 3068, 3069, 3083, 3084.



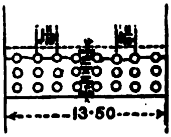
L 3068 1-inch.	**L 3083 1-inch.**	**L 3069 1-inch.**	**L 3084 1-inch.**
Punched.	*Punched.*	*Punched and annealed.*	*Punched and annealed.*
S.C. of S.L.G.S.	S.C. of S.L.G.S.	S.C. of S.L.G.S.	S.C. of S.L.G.S.
12·00 × ·99	12·00 × ·99	12·00 × ·99	12·00 × ·99
11·88	11·88	11·88	11·88
lbs. tons. 350,870 = 156·6	lbs. tons. 365,520 = 163·2	lbs. tons. 469,720 = 209·7	lbs. tons. 478,330 = 213·5
29,534 = 13·2	*30,767 = 13·7*	*39,538 = 17·6*	*40,263 = 18·0*
62,342 = 27·8	*61,862 = 27·6*	*62,342 = 27·8*	*61,862 = 27·6*
47·4	*49·7*	*63·4*	*65·1*
100% Granular	3% Silky 97% Granular	83% Silky 17% Granular	100% Silky
1·08 × 4 = 4·32	1·08 × 4 = 4·32	1·08 × 4 = 4·32	1·08 × 4 = 4·32
·06 + ·01 = ·07	·08 + ·04 = ·12	·45 + ·23 = ·68	·41 + ·20 = ·61
3·2	*5·5*	*31·4*	*28·2*
64·0	64·0	64·0	64·0

(Signed) **DAVID KIRKALDY,**
99, Southwark Street,
London, S.E., 3rd May 1878.

TABLE 6.

RESULTS of EXPERIMENTS to ascertain the ULTIMATE TENSILE
from STEEL PLATES and RIVETS. Messrs.

Nominal thicknesses :

Sketch of Joint with Sizes	
Test number and thickness - - -	L 2980 ¼-inch.
Description of joint - - - -	Lap, Triple riveted
Machine or hand riveted - -	Machine
Rivet holes - - - -	*Drilled*
Plates, brand - - - -	S. C. of S.L.G.S.
Plates, width and thickness - - . -	13·50 × ·25
Plates, sectional area, gross - - -	3·375
Stress, total - - - -	lbs. tons. 199,320 = 89·0
Stress per square-inch of gross area joint -	*59,058 = 26·3*
Stress per square-inch of plates, solid -	*70,765 = 31·6*
Ratio of joint to solid plate, per-centage -	*83·4*
Where fractured - - - -	Plate at rivet holes lengthway, 100 °/₀ Silky
Rivets, diameter, area, and number - -	Steel ·45 = ·159 × 24 × 1
Rivets, sectional area total square inches -	3·816
Shearing stress per square inch of rivet area	*52,232 = 23·3*
Tensile stress per square inch of rivet area -	*69,845 = 31·2*
Ratio of shearing to tensile per-centage -	Rivets not sheared

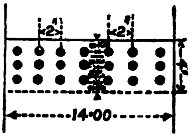
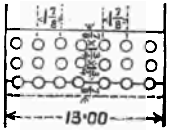
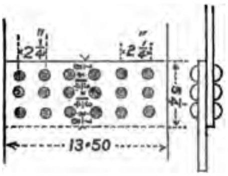
The holes were drilled here and the

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

TABLE 6.

STRENGTH of FOUR RIVETED JOINTS made to your Instructions The Steel Company of Scotland.

quarter and half-inch.

		
2995 ¼-inch	L 3010 ½-inch	L 3025 ½-inch
Lap, Triple riveted	Lap, Triple riveted	Lap, Triple riveted
Machine	Machine	Machine
Drilled	*Drilled*	*Drilled*
S. C. of S.L.G.S.	S.C. of S.L.G.S.	S. C. of S.L.G.S.
14·00 × ·24	13·00 × ·51	13·50 × ·51
3·360	6·630	6·885
lbs. tons. 188,140 = 84·0	lbs. tons. 332,640 = 148·5	lbs. tons 330,180 = 147·4
55,994 = 25·0	*50,172 = 22·3*	*47,956 = 21·5*
70,910 = 31·7	*65,300 = 29·1*	*65,300 = 29·1*
79·0	*76·8*	*73·4*
21 rivets sheared	Plate at rivet holes crossway, 95 °/ₒ Silky 5°/ₒ Granular	18 rivets sheared
Steel·45=·159 × 21 × 1	Steel·64=·321 × 21 × 1	Steel ·64 =·321 × 18 × 1
3·339	6·741	5·778
56,346= 25·1	*49,346 = 22·0*	*57,144 – 25·5*
69,845 = 31·2	*68,550* = 30·6	*68,550 = 30·6*
80·7	Rivets not sheared	84·2

plates riveted together by Messrs. J. and G. Rennie.

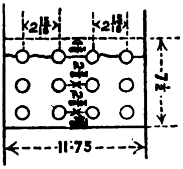
(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 8th May 1878.

F 2

TABLE 7.

RESULTS of EXPERIMENTS to ascertain the ULTIMATE TENSILE from STEEL PLATES and RIVETS. Messrs.

Nominal thicknesses

Sketch of Joint with Sizes.	
Test number and thickness	L 3040 ¾ inch
Description of joint	Lap, Triple riveted
Machine or hand riveted	Machine.
Rivet holes	*Drilled.*
Plates, brand	S.C. of S.L.G.S.
Plates, width and thickness	11·75 × ·78
Plates, sectional area gross	9·165
Stress, total	lbs. tons. 423,180 = 188·9
Stress per square-inch of gross area, joint	*46,173 = 20·6*
Stress per square-inch of plates, solid	*64,050 = 28·6*
Ratio of joint to solid plate per-centage	*72·1*
Where fractured	Plate at rivet holes crossway, 100°/$_{0}$ Silky
Rivets, diameter, area and number	Steel ·95 = ·708 × 12 × 1
Ratio sectional area, total square inches	8·496
Shearing stress per square inch of rivet area	*49,809 = 22·2*
Tensile stress per square inch of rivet area	*64,203 = 28·6*
Ratio of shearing to tensile, per-centage	Rivets not sheared

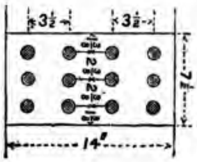
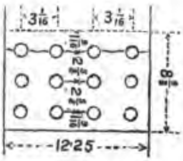
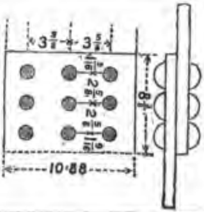
The holes were drilled here and the plates

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

TABLE 7.*

STRENGTH of FOUR RIVETED JOINTS made to your Instructions The Steel Company of Scotland.

three-quarter and one inch.

		
L 3055 ¾ inch	L 3070 1 inch	L 3085 1 inch
Lap, Triple riveted	Lap, Triple riveted	Lap, Triple riveted
Machine.	Machine.	Machine.
Drilled.	*Drilled.*	*Drilled.*
S.C. of S.L.G.S.	S.C. of S.L.G.S.	S.C. of S.L.G.S.
14·00 × ·77	12·25 × 1·01	10·88 × 1·00
10·780	12·372	10·880
lbs. tons. 455,210 = 203·2	lbs. tons. 528,240 = 235·8	lbs. tons. 446,220 = 199·2
42,227 = 18·8	*42,696 = 19·1*	*41,013 = 18·3*
68,045 = 30·4	*62,280 = 27·7*	*61,505 = 27·5*
62·1	*68·5*	*66·7*
12 rivets sheared	Plate at rivet holes crossway 70°/o Silky, 30°/o Granular.	9 rivets sheared
Steel ·95 = ·708 × 12 × 1	Steel 1·08 = ·916 × 12 × 1	Steel 1·08 = ·916 × 9 × 1
8·496	10·992	8·244
53,579 = 23·9	*48,057 = 21·5*	*54,127 = 24·1*
64,203 = 28·6	*67,585 = 30·2*	*67,585 = 30·2*
83·4	Rivets not sheared	80·1

riveted together by Messrs. J. & G. Rennie.

(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 8th May 1878.

TABLE 8.

ESULT of EXPERIMENTS to ascertain the TENSILE STRENGTH AND QUALITY of the
and RIVETS. Messrs. The

ominal size of Rivets and corresponding Nos. of Joints.	Test No.	Original		Stress.		Ratio of Elastic to Ultimate.	Fracture.				Stress per square inch of Fractured Area.	Extension.		Appearance of Fracture.
		Diameter.	Area.	Elastic per square inch.	Ultimate per square inch.		Diameter.	Area.	Difference.					
									Area.	pr. cent.				
	M.	in.	in	lbs.=tons.	lbs.=tons.	per cent	in.	sq. in.	sq. in.	per cent	lbs.			
ivets $\frac{7}{16}$" L 2995 L 2980	741	·357	·100	48,700=21·7	72,450=32·3	67·2	·19	·028	·072	72·0	258,750	Too short for ascertaining the Extensions.		Silky
	739	do.	do.	46,500=20·7	69.660=31·1	66·7	·20	·031	·069	69·0	224,709			do.
	738	do.	do.	45,600=20·3	68,780=30·7	66·2	·21	·034	·066	66·0	202,294			do.
	740	do.	do.	45,400=20·2	68,490=30·6	66·2	·20	·031	·069	69·0	220,935			do.
Mean -	—	—	—	**46,550=20·7**	**69,845=31·2**	**66·6**	—	—	—	**69·0**	**226,672**			
Rivets $\frac{1}{2}$" L 3025 L 3010	745	·451	·160	46,200=20·6	69,530=31·0	66·4	·28	·061	·099	61·9	182,373			Silky
	742	do.	do.	45,900=20·5	68,740=30·7	66·7	·26	·053	·107	66·9	207,517			do.
	744	do.	do.	45,800=20·5	68,620=30·7	66·7	·28	·061	·099	61·9	179,987			do.
	743	do.	do.	43,600=19·5	67,310=30·0	64·7	·27	·057	·103	64·4	188,940			do.
Mean	—	—	—	**45,375=20·3**	**68,550=30·6**	**66·1**	—	—	—	**63·8**	**189,704**			

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

TABLE 8.

EEL RIVETS used by Messrs. J. & G. RENNIE in RIVETED JOINTS of STEEL PLATES
eel Company of Scotland.

Rivets and corresponding Nos. of Joints.	Test No.	Original		Stress.		Ratio of Elastic to Ultimate.	Fracture.				Stress per square inch of Fractured Area.	Extension.	Appearance of Fracture.
		Diameter.	Area.	Elastic per square inch.	Ultimate per square inch.		Diameter.	Area.	Difference. Area.	Difference. pr. cent.			
	M.	in.	in.	lbs.=tons.	lbs.=tons.	pr. cent.	in.	sq. in.	sq. in.	pr. cent.	lbs.		
	749	·714	·400	39,900=17·8	65,690=29·3	60·7	·43	·145	·255	63·7	181,213	Too short for ascertaining the Extensions.	Silky
	748	do.	do.	39,700=17·7	64,970=29·0	61·1	·43	·145	·255	63·7	179,227		do.
ivets $\frac{15}{16}$'' 3055 3040	746	do.	do.	39,100=17·5	63,610=28·4	61·4	·43	·145	·255	63·7	175,475		do.
	747	do.	do.	38,600=17·2	62,540=27·9	61·7	·44	·152	·248	62·0	164,578		do
Iean -	—	—	—	**39,325=17·5**	**64,203=28·6**	**61·2**	—	—	—	**63·3**	**175,123**		
	753	·798	·500	42,200=18·8	68,280=30·5	61·8	·49	·188	·312	62·4	181,595		Silky
	750	do.	do.	41,800=18·6	67,580=30·1	61·8	·49	·188	·312	62·4	179,734		do.
Rivets $1\frac{1}{16}$'' 3085 3070	752	do.	do.	40,500=18·1	67,560=30·1	59·9	·50	·196	·304	60·8	172,346		do
	751	do.	do.	40,100=17·9	66,920=29·8	59·9	·50	·196	·304	60·8	170,714		do
n -	—	—	—	**41,150=18·3**	**67,585=30·1**	**60·8**	—	—	—	**61·6**	**176,097**		

(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, 4th May 1878.

TABLE 9.

RESULTS OF EXPERIMENTS to ascertain the RESISTANCE to BENDING

Distance between supports ten inches. Nominal thicknesses: quarter,

Tested in same condition as received.										
Stamped.	Lengthway.					Crossway.				
	Test No.	Thickness.	Stress.	Angle.	Effects.	Test No.	Thickness.	Stress.	Angle.	Effects.
	L.	inch.	lbs.	degrees		L.	inch.	lbs.	degrees	
4	2981	0·25	1,103	180	Uncracked.	2,982	0·25	1,085	180	Cracked slightly.
4	2996	0·24	1,145	180	Do.	2,997	0·24	1,100	180	Do.
2	3011	0·52	4,411	180	Do.	3,012	0·52	4,385	180	Do.
2	3026	0·52	4,330	180	Cracked slightly.	3,027	0·52	4,492	180	Do.
9	3041	0·77	10,240	140	Broken.	3,042	0·78	10,960	140	Cracked
0	3056	0·77	11,292	180	Uncracked.	3,057	0·77	11,331	180	Do.
7·8	3071	0·99	17,496	180	Do.	3,072	1·00	17,276	130	Broken.
7·8	3086	1·00	17,964	180	Do.	3,087	1·01	17,424	120	Do.

All planed exactly 2·5 inches wide.

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster. S.W.

TABLE 9.

STRESS of EIGHT STEEL PLATES. Messrs. The Steel Company of Scotland.

half, three-quarter, and one inch. Distance between supports ten inches.

After being heated and cooled in water.

Stamped.	Lengthway.					Crossway.				
	Test No.	Thickness.	Stress.	Angle.	Effects.	Test No.	Thickness.	Stress.	Angle.	Effects.
	L.	inch.	lbs.	degrees		L.	inch.	lbs.	degrees	
4	2983	0·25	1,126	180	Uncracked.	2,984	0·25	1,091	160	Cracked slightly.
4	2998	0·24	1,164	180	Do.	2,999	0·24	1,143	180	Cracked.
2	3013	0·52	4,596	180	Cracked slightly.	3,014	0·52	4,544	180	Cracked slightly.
2	3028	0·52	4,550	180	Uncracked.	3,029	0·52	4,582	170	Do.
9	3043	0·77	11,784	180	Cracked	3,044	0·77	11,411	150	Broken.
0	3058	0·77	12,032	180	Do.	3,059	0·76	12,538	70	Do.
7·8	3073	0·99	19,016	150	Broken.	3,074	1·00	20,444	68	Do.
7·8	3088	1·00	20,468	135	Do.	3,089	1·01	20,288	110	Do.

All planed exactly 2·5 inches wide.

(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 18th May 1878.

TABLE 10.

RESULTS of EXPERIMENTS to ascertain the RESISTANCE to BULGING STRESS of STEEL PLATES.

Messrs. The Steel Company of Scotland.

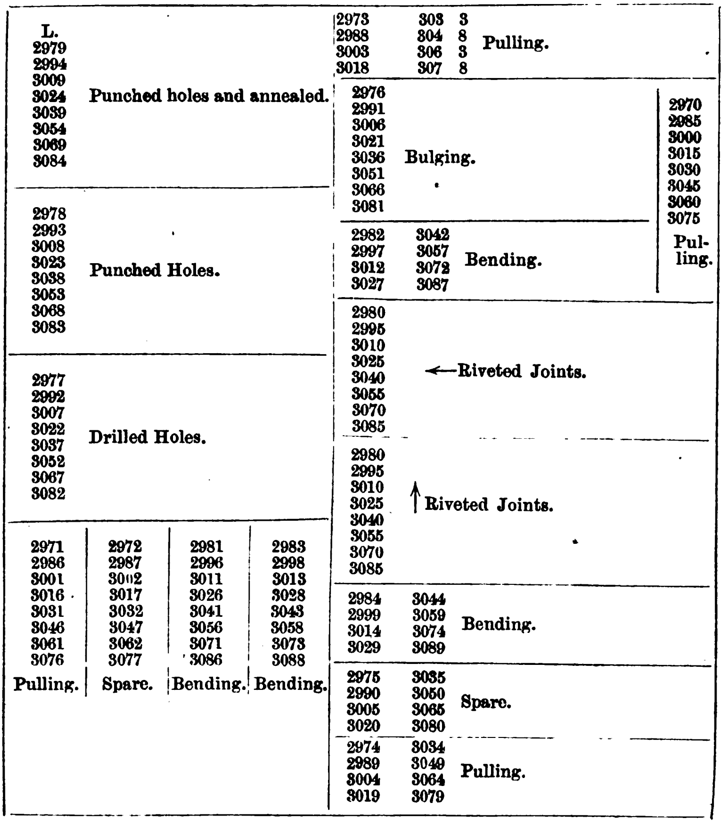
Nominal thicknesses: quarter, half, and three-quarters-inch.

amped.	Test No.	Thickness.	Stress in pounds. Bulged inches.												Ultimate.		Effects.
			25,000	50,000	75,000	100,000	125,000	150,000	175,000	200,000	225,000	250,000	275,000	300,000	Bulge.	Stress.	
	L.	inch.													inch.	lbs.	
4	2976	·25	0 ·76	1·46	2·06	—	—	—	—	—	—	—	—	—	3·02	86,350	Uncracked.
4	2991	·24	0·78	1·50	2·18	—	—	—	—	—	—	—	—	—	3·02	82,320	do.
2	3006	·52	0·46	1·00	1·40	1·70	1·98	2·27	2·66	—	—	—	—	—	3·22	188,930	do.
2	3021	·52	0·43	0·95	1·33	1·67	1·93	2·24	2·64	—	—	—	—	—	3·22	185,180	do.
9	3036	·77	0·22	0·50	0·80	1·11	1·34	1·54	1·75	1·94	2·10	2·30	2·48	2·7	3·45	335,210	Cracked.
0	3051	·77	0 ·21	0·48	0·77	1·04	1·32	5 4	1·68	1·86	1·99	2·17	2·38	2·5	3·45	341,240	do.

Disc twelve inches diameter cut out of plates, and pressed into aperture ten inches diameter.

TABLE 11.

SKETCH showing Position of Specimens, the Number being all stamped on the Plates previous to the pieces being cut off.



Dimensions of plates six feet by three feet.

Thomas W. Traill, Esq.
The Engineer Surveyor-in Chief,
13, Downing Street, Westminster, S.W.

(Signed) DAVID KIRKALDY,
99, Southwark Street, London, S.E.
20th May 1878.

Table 12.

Summary of the Results of Experiments to ascertain the Elastic and Ultimate Tensile Strength of Twelve Pieces of Steel Plates, received from Garston.

Nominal thicknesses : quarter, three-eighths, and half inch.

			Stress.					Extension Set in ten Inches.			
	Test No.	Thickness.	Elastic per square inch.	Ultimate per square inch.	Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Stress per square inch of Fractured Area.	At 50,000 lbs. per sq. in.	At 60,000 lbs. per sq. in.	Ultimate.	Appearance of Fracture.
Lengthway.	M.	inch.	lbs. tons.	lbs. tons.	per cent.	per cent.	lbs.	per cent.	per cent.	per cent.	
1 W.	1703	·26	39,800=17·7	68,910=30·7	57·7	50·2	138,351	1·49	5·18	20·9	Silky.
6 W.	1713	·28	39,500=17·6	68,720=30·6	57·4	48·9	134,555	1·81	6·03	26·2	do.
5 W.	1711	·38	37,300=16·6	68,440=30·5	54·5	45·0	124,435	3·60	7·61	27·8	do.
2 W.	1705	·50	35,700=16·0	65,960=29·5	54·1	46·1	122,374	4·18	9·50	28·8	do.
3 W.	1707	·50	35,500=15·8	65,710=29·3	54·0	43·9	117,130	4·39	9·70	26·2	do.
4 W.	1709	·38	34,400=15·3	63,780=28·5	53·9	49·7	126,890	4·84	11·10	29·6	do.
		Mean	**37,033=16·5**	**66,920=30·0**	**55·3**	**47·3**	**127,289**	**3·38**	**8·19**	**26·6**	
Crossway.											
1 A.	1717	·27	39,800=17·7	67,880=30·2	58·6	42·0	117,108	1·12	6·22	18·6	Silky.
6 A.	1727	·27	39,600=17·6	67,490=30·1	58·6	42·2	116,807	1·58	6·36	18·8	do,
5 A.	1725	·38	36,800=16·5	65,840=29·4	55·9	41·0	111,691	3·95	8·91	22·9	do.
4 A.	1723	·39	36,400=16·2	65,280=29·1	55·7	42·9	114,422	4·77	9·90	23·8	do.
2 A.	1719	·52	32,700=14·5	64,920=29·0	50·3	46·3	120,996	5·21	11·40	28·8	do.
3 A.	1721	·51	32,300=14·4	63,960=28·5	50·5	42·6	111,519	5·38	12·80	25·7	do.
		Mean	**36,266=16·2**	**65,895=29·5**	**54·9**	**42·8**	**115,424**	**3·67**	**8·26**	**23·1**	

M. 1709, 1717, 1721, 1723, 1725. Branded

(Signed) David Kirkaldy,
99, Southwark Street, London, S.E.,
19th June 1878.

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, S.W.

TABLE 13.

SUMMARY of the RESULTS of EXPERIMENTS to ascertain the Elastic
Messrs. The Steel Co

Nominal thicknesses : quarter,

Lengthway.

Stamped.	Test No.	Thickness.	Stress.		Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Stress per square inch of Fractured Area.	Extension Set in ten inches.			Appearan of Fracture
			Elastic per square inch.	Ultimate per square inch.				At 50,000 lbs. per sq. in.	At 60,000 lbs. per sq. in.	Ultimate.	
	M.	inch	lbs. tons.	lbs. tons.	per cent.	per cent.	lbs.	per cent.	per cent.	per cent.	
287	2796	·25	39,500=17·6	68,710=30·6	57·4	42·0	118,465	1·72	7·81	26·4	100 % Silk
	2797	·25	36,800=16·4	67,620=30·2	54·4	47·6	129,045	3·81	8·60	26·0	Do.
		Mean	**38,150=17·0**	**68,165=30·4**	**55·9**	**44·8**	**123,755**	**2·76**	**8·20**	**26·2**	
288	2808	·50	35,100=15·6	64,620=28·8	54·3	56·2	147,534	5·01	11·2	30·1	Do.
	2807	·50	35,200=15·6	64,410=28·7	54·3	58·2	154,090	4·96	11·6	30·5	Do.
		Mean	**35,150=15·6**	**64,515=28·7**	**54·3**	**57·2**	**150,812**	**4·98**	**11·4**	**30·3**	
290	2818	·73	35,500=15·8	65,885=29·4	53·8	36·0	102,989	4·51	9·9	27·5	97 % Silk 3% blist
	2817	·72	35,300=15·7	65,570=29·2	53·8	52·3	137,638	4·75	10·1	30.7	100 % Sil
		Mean	**35,400=15·7**	**65,727=29·3**	**53·8**	**44·1**	**120,313**	**4·63**	**10·0**	**29·1**	
289	2827	1·02	34,800=15·5	64,310=28·6	54·1	55·0	143,222	5·31	11·2	31·4	Do.
	2828	1·00	33,600=15·0	62,865=28·1	53·4	55·2	140,323	5·98	13·5	31·8	Do.
		Mean	**34,200=15·2**	**63,587=28·4**	**53·7**	**55·1**	**141,772**	**5·64**	**12·3**	**31·6**	

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

TABLE 13.

and Ultimate Tensile Stress of FOUR STEEL PLATES, received Direct from
of Scotland.

half, three quarters, and one inch.

Crossway.

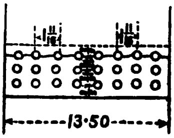
Stamped.	Test No.	Thickness.	Stress.		Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Stress per square inch of Fractured Area.	Extension Set in ten Inches.			Appearanc of Fracture.
			Elastic per square inch.	Ultimate per square inch.				At 50,000 lbs. per sq. in.	At 60,000 lbs. per sq. in.	Ultimate.	
	M.	inch.	lbs. tons.	lbs. tons.	per cent.	per cent.	lbs.	per cent.	per cent.	per cent.	
287	2800	·25	39,300=17·5	68,320=30·5	57·5	36·6	107,760	2·53	7·24	23·6	100 °/o Silky
	2799	·25	36,400=16·2	65,840=29·4	55·2	43·2	115,915	4·50	9·80	26·8	Do.
		Mean	**37,850=16·8**	**67,080=29·9**	**56·3**	**39·9**	**111,837**	**3·51**	**8·52**	**25·2**	
288	2809	·50	34,800=15·5	63,480=28·5	54·8	47·6	121,141	5·39	13·1	30·8	Do.
	2810	·50	34,200=15·2	62,140=27·7	55·0	41·2	105,680	6·08	15·6	31·2	Do.
		Mean	**34,500=15·3**	**62,810=28·0**	**54·9**	**44·4**	**113,410**	**5·73**	**14·3**	**31·0**	
290	2820	·73	35,200=15·6	64,405=28·7	54·6	31·7	94,313	5·02	11·1	26·3	Do.
	2819	·72	35,100=15·6	64,360=28·6	54·5	50·6	130,532	5·47	11·5	28·1	95 °/o silky 5°/o granula
		Mean	**35,150=15·6**	**64,383=28·7**	**54·5**	**41·1**	**112,422**	**5·24**	**11·3**	**27·2**	
289	2829	1·00	34,400=15·3	64,830=28·9	53·0	49·3	127,996	4·60	10·2	26·2	100 °/o Silky
	2830	1·02	33,200=14·8	62,540=27·9	53·0	44·9	113,204	5·96	13·9	27·6	Do.
		Mean	**33,800=15·1**	**63,685=28·4**	**53·0**	**47·0**	**120,600**	**5·28**	**12·0**	**26·9**	

(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 20th November 1878.

TABLE 14.

RESULT of EXPERIMENTS to ascertain the ULTIMATE TENSILE from STEEL PLATES and RIVETS. Messrs.

Nominal thicknesses

Sketch of Joint with Sizes.	
Test number and thickness	M 2801 ¼ inch
Description of joint	Lap, Triple riveted
Machine or hand riveted	Machine.
Rivet holes	*Punched.*
Plates, brand	Steel Co. of Scotland.
Plates, width and thickness	13·50 × ·25
Plates, sectional area, gross	3·375
Stress, total	lbs. tons. 172,830 = 77·1
Stress per square inch of gross area, joint	*51,209 = 22·8*
Stress per square inch of plates, solid	*67,080 = 29·9*
Ratio of joint to solid plate per-centage	*76·3*
Where fractured	Plate at rivet holes crossway, 100 °/o Silky
Rivets, diameter, area, and number	Steel ·47 = ·173 × 24 × 1
Rivets, sectional area, total square inches	4·152
Shearing stress per square inch of rivet area	*41,525 = 18·5*
Tensile stress per square inch of rivet area	*73,310 = 32·7*
Ratio of shearing to tensile per-centage	Rivets not sheared

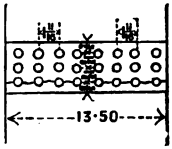
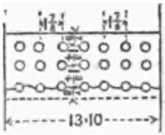
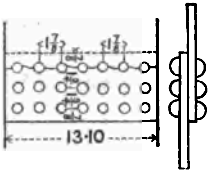
The holes were punched and the plates riveted together by Messrs. J. and

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

TABLE 14.

STRENGTH of FOUR RIVETED JOINTS made to your Instructions The Steel Company of Scotland.

quarter and half-inch.

		
M 2802 ¼ inch	**M 2811 ½ inch**	**M 2812 ½ inch**
Lap, Triple riveted	**Lap, Triple riveted**	**Lap, Triple riveted**
Machine.	**Machine.**	**Machine.**
Punched annealed.	***Punched.***	***Punched annealed.***
Steel Co. of Scotland.	**Steel Co. of Scotland.**	**Steel Co. of Scotland.**
13·50 × ·25	**13·10 × ·50**	**13·10 × ·50**
3·375	**6·550**	**6·550**
lbs. tons. **179,180 = 80·0**	**lbs. tons.** **287,470 = 128·3**	**lbs. tons.** **305,980 = 136·6**
53,090 = 23·7	***43,889 = 19·6***	***46,715 = 20·9***
67,080 = 29·9	***62,810 = 28·0***	***62,810 = 28·0***
79·1	***69·9***	***74·4***
Plate at rivet holes crossway, 100°/₀ Silky	**Plate at rivet holes crossway, 60 °/₀ Silky, 40 °/₀ Granular**	**Plate at rivet holes crossway, 100 °/₀ Silky**
Steel, ·47 = ·173 × 24 × 1	**Steel, ·66 = ·342 × 21 × 1**	**Steel, ·66 = ·342 × 21 × 1**
4·152	**7·182**	**7·182**
43,155 = 19·2	***40,026 = 17·8***	***42,604 = 19·0***
73,310 = 32·7	***67,197 = 30·0***	***67,197 = 30·0***
Rivets not sheared	**Rivets not sheared**	**Rivets not sheared**

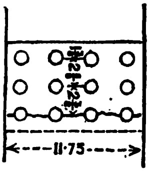
G. Rennie; they also annealed previous to riveting, these plates marked above.

(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 20th Nov. 1878.

TABLE 15.

RESULTS of EXPERIMENTS to ascertain the ULTIMATE TENSILE
from STEEL PLATES and RIVETS. Messrs.

Nominal thicknesses

Sketch of Joint with Sizes.	
Test number and thickness - - -	M 2821, ¾-inch
Description of joint - - - -	Lap, Triple riveted
Machine or hand riveted - - -	Machine
Rivet holes - - - -	*Punched*
Plates, brand - - - - -	Steel Co. of Scotland.
Plates, width and thickness - - -	11·75 × ·725
Plates, sectional area, gross - - -	8·519
Stress total - - - - -	lbs. tons. 354,860 = 158·4
Stress per square inch of gross area, joint -	*41,655 = 18·6*
Stress per square inch of plates, solid - -	*64,383 = 28·7*
Ratio of joint to solid plate per-centage -	*64·7*
Where fractured - - - -	Plate at rivet holes crossway 100°/₀ granular
Rivets, diameter, area, and number - -	Steel ·97 = ·739 × 12 × 1
Rivets, sectional area, total square inches -	8·868
Shearing stress per square inch of rivet area -	*40,016 = 17·9*
Tensile stress per square inch of rivet area -	*71,165 = 31·8*
Ratio of shearing to tensile, per-centage -	Rivets not sheared

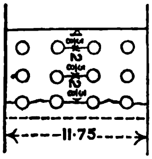
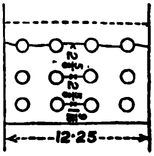
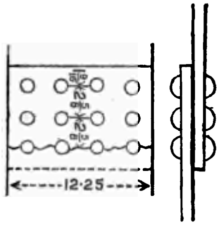
The holes were punched and the plates riveted together by Messrs. J. and G.

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
18, Downing Street, Westminster, S.W.

Table 15.

Strength of four **Riveted Joints** made to your Instructions The Steel Company of Scotland.

three-quarters and one inch.

		
M 2822, ¾-inch	M 2831, 1 inch	M 2832, 1 inch.
Lap, Triple riveted	Lap, Triple riveted	Lap, Triple riveted
Machine	Machine	Machine
Punched annealed	*Punched*	*Punched annealed*
Steel Co. of Scotland.	Steel Co. of Scotland.	Steel Co. of Scotland.
11·75 × ·725	12·25 × 1·01	12·25 × 1·01
8·519	12·372	12·372
lbs. tons. 391,070 = 174·6	lbs. tons. 242,780 = 108·4	lbs. tons. 526,240 = 234·9
45,906 = 20·6	*19,623 = 8·8*	*42,534 = 19·0*
64,383 = 28·7	*63,685 = 28·4*	*63,685 = 28·4*
71·3	*30·8*	*66·8*
Plate at rivet holes crossway 25°/o silky, 75°/o granular	Plate at rivet holes crossway 100°/o granular	Plate at rivet holes crossway 10°/o silky, 90°/o granular
Steel ·97 = ·739 × 12 × 1	*Steel* 1·09 = ·933 × 12 × 1	*Steel* 1·09 = ·933 × 12 × 1
8·868	11·196	11·196
44,099 = 19·7	*21,684 = 9·7*	*47,002 =* 21·0
71,165 = 31·8	*67,387 = 30·1*	*67,387 = 30·1*
Rivets not sheared	Rivets not sheared	Rivets not sheared

Rennie, they also annealed, previous to riveting, these plates marked above.

(Signed) David Kirkaldy,
99, Southwark Street, London, S.E.
20th November 1878.

TABLE 16.

RESULTS of EXPERIMENTS to ascertain the TENSILE STRENGTH and QUALITY of the STEEL RIVETS used by Messrs. J. & G. RENNIE in RIVETED JOINTS of STEEL PLATES. Messrs. The Steel Company of Scotland.

Nominal size of Rivets and corresponding Nos. of Joints.	Test No.	Original.		Stress.		Ratio of Elastic to Ultimate.	Fractured.				Stress per square inch of Fractured Area.	Extension.		Appearance of Fracture.
		Diameter.	Area.	Elastic per square inch.	Ultimate per square inch.		Diameter.	Area.	Difference.					
									Area.	pr. cent.				
	M.	in.	sq. in.	lbs. tons.	lbs. tons.	pr. cent.	in.	sq. in.	sq. in.	pr. cent.	lbs.			
Rivets 7/16″ M 2801 M 2802	3199	·357	·100	48,500=21·6	75,120=33·5	64·5	·20	·031	·069	69·0	242,322	Too short for ascertaining the Extension.		Silky.
	3198	do.	do.	47,700=21·2	74,510=33·2	64·0	·21	·035	·065	65·0	212,885			do.
	3196	do.	do.	47,300=21·1	73,040=32·6	64·7	·21	·035	·065	65·0	208,685			do.
	3197	do.	do.	45,200=20·1	70,570=31·5	64·0	·20	·031	·069	69·0	227,645			do.
Mean -	—	—	—	**47,175=21·0**	**73,310=32·7**	**64·3**	—	—	—	**67·0**	**222,884**			
Rivets 5/8″ M 2811 M 2812	3203	·561	·160	41,700=18·6	68,830=30·7	60·5	·26	·053	·107	66·8	207,765			Silky.
	3202	do.	do.	41,400=18·5	67,960=30·3	60·9	·27	·057	·103	64·3	190,754			do.
	3200	do.	do.	40,800=18·2	66,420=29·6	61·4	·27	·057	·103	64·3	186,438			do.
	3201	do.	do.	40,500=18·1	65,580=29·2	61·7	·27	·057	·103	64·3	184,070			do.
Mean -	—	—	—	**41,100=18·3**	**67,197=30·0**	**61·1**	—	—	—	**64·9**	**192,257**			
Rivets 15/16″ M 2821 M 2822	3204	·714	·400	41,900=18·6	72,640=32·3	57·6	·47	·173	·227	56·7	167,953			Silky.
	3206	do.	do.	41,600=18·5	71,020=31·6	58·5	·43	·145	·255	63·7	195,917			do.
	3205	do.	do.	40,800=18·2	70,710=31·5	57·7	·46	·166	·234	58·5	170,385			do.
	3207	do.	do.	40,400=18·0	70,290=31·4	57·4	·45	·159	·241	60·2	176,830			do.
Mean -	—	—	—	**41,175=18·3**	**71,165=31·7**	**57·8**	—	—	—	**59·8**	**177,771**			
Rivets 1 1/16″ M 2831 M 2832	3208	·798	·500	39,900=17·7	72,680=32·3	54·8	·50	·196	·304	60·8	185,408			Silky
	3209	do.	do.	39,500=17·6	70,260=31·4	56·2	·51	·204	·296	59·2	172,205			do.
	3211	do.	do.	35,800=16·0	63,850=28·5	56·0	·53	·221	·279	55·8	144,457			do.
	3210	do.	do·	35,500=15·7	62,760=28·0	56·5	·48	·181	·319	63·8	173,370			do.
Mean -	—	—	—	**37,675=16·7**	**67,387=30·0**	**55·8**	—	—	—	**59·9**	**168,860**			

Thomas W. Traill, Esq., (Signed) DAVID KIRKALDY,
The Engineer Surveyor-in-Chief, 99, Southwark Street,
13, Downing Street, Westminster, S.W. London, S.E. 20th Nov. 1878.

TABLE 17.

RESULTS of EXPERIMENTS to ascertain the resistance to BENDING STRESS of FOUR STEEL PLATES. Messrs. The Steel Company of Scotland.

Distance between supports, ten inches. Nominal thicknesses, quarter, half, three quarters and one inch. Distance between supports ten inches.

TESTED IN SAME CONDITION AS RECEIVED.

Brand and Stamped.	Lengthway.					Crossway.				
	Test No.	Thickness.	Stress.	Angle.	Effects.	Test No.	Thickness.	Stress.	Angle.	Effects.
Steel Company of Scotland.	M.	inch.	lbs.	degrees.		M.	inch.	lbs.	degrees.	
287	2803	·25	1,078	180	Uncracked	2,804	·25	1,121	180	Cracked.
288	2813	·50	4,172	180	Uncracked	2,814	·50	4,009	180	Uncracked.
290	2823	·72	9,611	180	Uncracked	2,824	·73	9,414	180	Cracked slightly.
289	2833	1·00	19,076	180	Uncracked	2,834	1·01	19,318	180	Uncracked.

AFTER BEING HEATED AND COOLED IN WATER UNDER MR. SAMSON'S DIRECTIONS.

Brand and Stamped.	Lengthway.					Crossway.				
	Test No.	Thickness.	Stress.	Angle.	Effects.	Test No.	Thickness.	Stress.	Angle.	Effects.
Steel Company of Scotland.	M.	inch.	lbs.	degrees.		M.	inch.	lbs.	degrees.	
287	2,805	·25	1,406	150	Cracked slightly.	2,806	·25	1,493	130	Cracked.
288	2815	·50	6,331	140	Cracked	2,816	·50	6,092	125	Broken.
290	2825	·73	13,164	65	Broken	2,826	·72	12,782	50	Broken.
289	2835	1·00	28,054	42	Broken	2,836	1·01	28,436	32	Broken.

All planed exactly 2·5 inches wide.

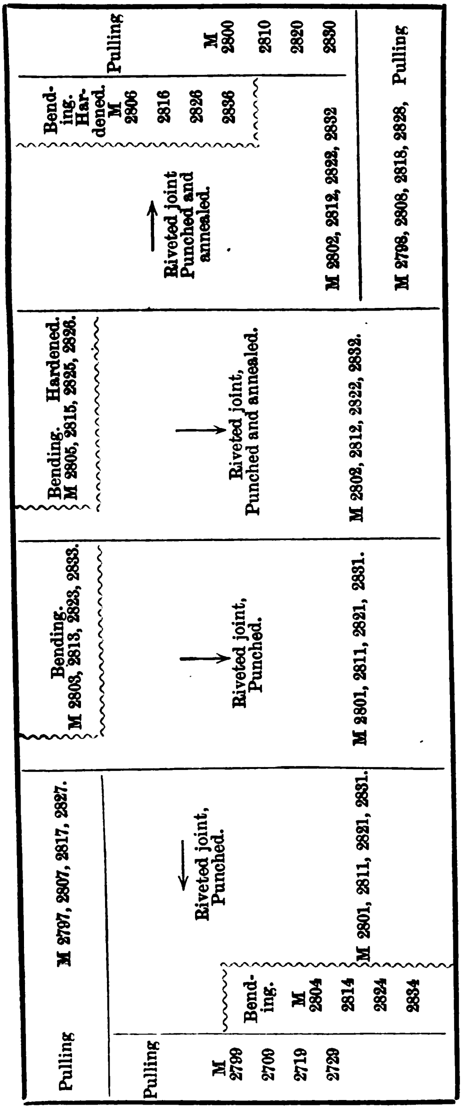
As plates are never subjected in actual practice to the above treatment I have always verbally objected to making such tests, and I now put my dissent on record.

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster, S.W.

(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 23rd Nov. 1878.

TABLE 18.

SKETCH showing POSITION of SPECIMENS, the Numbers being all stamped on the Plates previous to the pieces being cut off. Messrs. The Steel Company of Scotland.


Pulling
M 2800
2810
2820
2830
Bend-ing. Har-dened. M 2806
2816
2826
2836
Riveted joint Punched and annealed.
M 2802, 2812, 2822, 2832
M 2798, 2808, 2818, 2828, Pulling
Bending. Hardened.
M 2805, 2815, 2825, 2835.
Riveted joint, Punched and annealed.
M 2802, 2812, 2822, 2832.
Bending.
M 2803, 2813, 2823, 2833.
Riveted joint, Punched.
M 2801, 2811, 2821, 2831.
M 2797, 2807, 2817, 2827.
Riveted joint, Punched.
M 2801, 2811, 2821, 2831.
Bend-ing.
M 2804
2814
2824
2834
Pulling
Pulling
M 2799
2700
2719
2729

Dimensions of Plates, eight feet by two feet.

(Signed) DAVID KIRKALDY,
99, Southwark Street, London, S.E.
23rd November 1878.

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, Westminster.

TABLE 19.

PRELIMINARY TESTS—STEEL RIVETS.

Results of Experiments to ascertain the Tensile Strength, &c. of Sixteen Steel Rivets, received from Messrs. The Steel Company of Scotland.

Test No.	Description.	Original. Diameter.	Original. Area.	Ultimate Stress. Total.	Ultimate Stress. Per square inch of Original Area.		Fractured. Diameter.	Fractured. Area.	Fractured. Difference. Area.	Fractured. Difference. Per Cent.		Stress per square inch of Fractured area.	Extension. Inch.	Extension. Per Cent.	Appearance of Fracture.
		turned.	sq. in.		lbs.	lbs. tons.						lbs.			
L. 3757	7/16" dia.	·40	·126	8,848	70,222	69,019 30·8	·24	·045	·081	64·2	61·1	177,479	Too short for ascertaining the extension.		Silky.
3758	do.	do.	do.	8,774	69,634		·25	·049	·077	61·1					do.
3760	do.	do.	do.	8,608	68,317		·26	·053	·073	57·9					do
3759	do.	do.	do.	8,556	67,904		·25	·049	·077	61·1					do
3764	¾" dia.	·564	·250	14,928	59,712	59,196 26·5	·34	·091	·159	63·6	66·4	176,178			do.
3763	do.	do.	do.	14,856	59,424		·33	·085	·165	66·0					do.
3765	do.	do.	do.	14,834	59,336		·33	·085	·165	66·0					do.
3766	do.	do.	do.	14,578	58,312		·31	·075	·175	70·0					do
3771	1⅛" dia.	·874	·600	36,507	60,845	60,520 27·0	·58	·264	·336	56·0	52·8	128,387			do.
3772	do.	do.	do.	36,432	60,720		·59	·273	·327	54·5					do
3769	do.	do.	do.	36,183	60,305		·62	·302	·298	49·6					do.
3770	do.	do.	do.	36,084	60,210		·61	·292	·308	51·3					do.
3775	1¼" dia.	1·128	1·000	57,325	57,325	57,019 25·5	·71	·396	·604	60·4	60·9	146,014			do.
3776	do.	do.	do.	57,210	57,210		·69	·374	·626	62·6					do.
3778	do.	do.	do.	56,895	56,895		·72	·407	·593	59·3					do.
3777	do.	do.	do.	56,645	56,645		·70	·385	·615	61·5					do.

Thomas W. Traill, Esq.,
The Engineer Surveyor-in-Chief,
13, Downing Street, S.W.

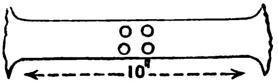
(Signed) DAVID KIRKALDY,
99, Southwark Street,
London, S.E., 20th Nov. 1877.

TABLE 20.

RESULTS of EXPERIMENTS upon STEEL PLATES manufactured by the Stress) of Punching, Annealing after Punching,

Nominal thickness

Perforated Specimen.



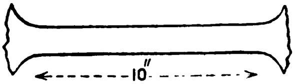
No. of Specimen.	Holes, how perforated.	Specimen if annealed.	Nominal Thickness.	Actual Thickness.	Width of Specimen.	Diameter of Holes.	Elongation of Holes at Ultimate Stress.	Net Sectional Area of Specimen.
1	2	3	4	5	6	7	8	9
			inch.	inch.	ins.	inch.	per cent.	sq. in.
25	Punched -	Not annealed	¼	·26	1·65	·26	11·5	·29
26	Do. -	Do.	¼	·26	1·66	·26	7·6	·29
27	Do. -	Annealed -	¼	·26	1·65	·26	34·6	·29
28	Do. -	Do.	¼	·26	1·65	·26	38·4	·29
29	Punched small and bored to size.	Not annealed	¼	·26	1·65	·25	20·0	·29
30	Do. -	Do.	¼	·26	1·65	·25	24·0	·29
31	Drilled -	Do.	¼	·26	1·66	·25	32·0	·30
32	No holes -	Do.	¼	·26	1·17	Nil	--	·30

TABLE 20.

STEEL COMPANY of SCOTLAND to ascertain the Effects (under Pulling Boring after Punching, and Drilling.

of Plate, ¼ inch.

Unperforated Specimen.



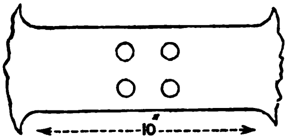
Total Stress. Ultimate.	Ultimate Stress per square inch of Gross Area.	Ultimate Stress per square inch between Holes.	Stress per Square Inch of Net Section compared with Solid Plate.	Contraction of Area at Fracture.	Extension Set in ten Inches.		
					At 50,000 lbs. per square inch of Net Area.	At 60,000 Lbs. per square inch of Net Area.	Ultimate.
10	11	12	13	14	15	16	17
lbs. tons.	lbs. tons.	lbs. tons.	per cent.	per cent.	per cent.	per cent.	per cent.
18,340 8·18	43,666 19·49	63,241 28·23	93·5	24·1	—	·2	1·9
18,480 8·25	42,976 19·18	63,724 28·44	94·2	24·1	—	·3	1·5
20,531 9·16	48,883 21·82	70,796 31·60	104·7	41·3	·1	·5	5·6
20,531 9·16	48,883 21·82	70,796 31·60	104·7	41·3	—	·4	6·1
20,055 8·95	47,750 21·31	69,155 30·87	102·3	20·6	·1	1·0	3·9
20,531 9·16	48,883 21·82	70,796 31·60	104·7	27·5	—	·3	4·6
21,147 9·44	49,179 21·95	70,490 31·46	104·2	36·6	·2	·5	5·8
20,279 9·05	67,596 30·17	67,596 30·17	—	53·3	3·5	12·0	22·9

TABLE 21.

RESULTS of EXPERIMENTS upon STEEL PLATES manufactured by the
Stress) of Punching, Annealing after Punching,

Nominal thickness

Perforated Specimen.



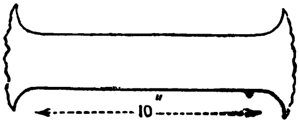
No. of Specimen.	Holes, how perforated.	Specimen if annealed.	Nominal Thickness.	Actual Thickness.	Width of Specimen.	Diameter of Holes.	Elongation of Holes at Ultimate Stress.	Net Sectional Area of Specimen.
1	2	3	4	5	6	7	8	9
			inch.	inch.	ins.	inch.	per cent.	sq. ins.
21	Punched -	Not annealed	½	·49	3·32	·5	14·0	1·13
24	Do. -	Do.	½	·5	3·32	·5	10·0	1·16
19	Do. -	Annealed -	½	·5	3·32	·5	40·0	1·16
20	Do. -	Do.	½	·5	3·32	·5	46·0	1·16
17	Punched small and bored to size.	Not annealed	½	·49	3·32	·49	30·6	1·14
18	Do.	Do.	½	·5	3·32	·49	26·5	1·17
22	Drilled -	Do.	½	·49	3·31	·5	44·0	1·13
23	No holes -	Do.	½	·5	2·32	Nil	—	1·16

Table 21.

Steel Company of Scotland to ascertain the Effects (under Pulling Boring after Punching, and Drilling.

of Plate, ½ inch.

Unperforated Specimen.



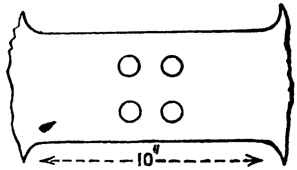
TotalStress. Ultimate.	Ultimate Stress per square inch of Gross Area.	Ultimate Stress per SquareInch between Holes.	Stress per square inch of Net Section compared with Solid Plate.	Contraction of Area at Fracture.	Extension Set in 10 Inches.		
					At 50,000lbs. per square inch of Net Area.	At 60,000 Lbs. per square inch of Net Area.	Ultimate.
10	11	12	13	14	15	16	17
lbs. tons.	lbs. tons.	lbs. tons.	per cent.	per cent.	per cent.	per cent.	per cent.
65,142 29·08	40,211 17·95	57,647 25·73	92·9	16·8	·5	Broken	3·2
64,820 28·93	39,048 17·43	55,879 24·94	90·0	21·5	·2	Broken	2·6
75,320 33·62	45,373 20·25	64,931 28·98	104·6	39·6	·9	2·5	8·0
77,448 34·57	46,655 20·82	66,765 29·80	107·6	35·3	·7	2·4	8·0
80,423 35·90	49,643 22·16	70,546 31·49	113·7	28·9	·4	2·1	6·7
79,240 35·37	47,734 21·30	67,726 30·23	109·1	29·0	·5	2·1	6·5
79,408 35·45	49,017 21·88	70,272 31·37	113·2	32·7	·9	2·9	7·8
71,953 32·12	62,028 27·69	62,028 27·69	—	50·0	4·8	13·5	30·3

TABLE 22

RESULTS of EXPERIMENTS upon STEEL PLATES manufactured by the
Stress) of Punching, Annealing after Punching,

Nominal thickness

Perforated Specimen.



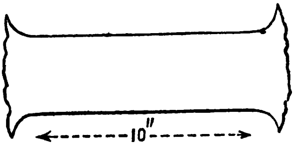
No. of Specimen.	Holes, how perforated.	Specimen if annealed.	Nominal Thickness.	Actual Thickness.	Width of Specimen.	Diameter of Holes.	Elongation Holes at Ultimate Stress.	Net Sectional Area of Specimen.
1	2	3	4	5	6	7	8	9
			inch.	inch.	ins.	inch.	per cent.	sq. ins
11	Punched -	Not annealed	¾	·75	4·96	·75	5·3	2·59
12	Do. -	Do.	¾	·74	4·95	·75	16·0	2·55
9	Do. -	Annealed -	¾	·75	4·95	·75	34·6	2·58
10	Do. -	Do.	¾	·74	4·95	·75	36·0	2·55
13	Punched small and bored to size.	Not annealed	¾	·75	4·96	·75	28·0	2·59
14	Do. -	Do.	¾	·75	4·95	·75	17·3	2·58
15	Drilled -	Do.	¾	·75	4·95	·75	32·0	2·58
16	No holes -	Do.	¾	·73	3·44	Nil	—	2·51

Table 22.

Steel Company of Scotland to ascertain the Effects (under Pulling Boring after Punching, and Drilling.

of Plate, ¾ inch.

Unperforated Specimen.



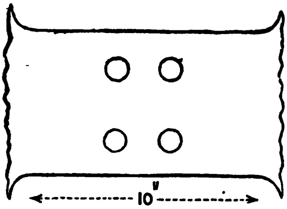
Total Stress. Ultimate.	Ultimate Stress per square inch of Gross Area.	Ultimate Stress per square inch between Holes.	Stress per square inch of Net Section compared with Solid Plates.	Contraction of Area at Fracture.	Extension Set in 10 Inches.		
					At 50,000 lbs. per square inch of Net Area.	At 60,000 Lbs. per square inch of Net Area.	Ultimate.
10	11	12	13	14	15	16	17
lbs. tons.	lbs. tons.	lbs. tons.	per cent.	per cent.	per cent.	per cent.	per cent.
122,360 54·62	32,892 14·68	47,243 21·09	75·7	7·7	Broken	Broken	·9
141,680 63·25	38,710 17·28	55,560 24·80	89·0	18·4	·8	Broken	4·0
167,608 74·82	45,177 20·16	64,964 29·00	104·1	28·6	1·6	3·7	8·2
169,232 75·55	46,238 20·64	66,365 29·62	106·3	32·9	1·5	4·0	8·8
173,040 77·25	46,516 20·76	66,810 29·82	107·1	28·9	·8	3·6	8·1
160,720 71·75	43,320 19·33	62,294 27·80	99·8	10·0	1·3	3·4	5·3
174,720 78·00	47,094 21·02	67,720 30·23	108·5	32·1	1·5	3·9	9·2
156,576 69·90	62,380 27·84	62,380 27·84	—	39·4	4·6	12·4	30·6

TABLE 23.

RESULTS of EXPERIMENTS upon STEEL PLATES manufactured by the
Stress) of Punching, Annealing after Punching,

Nominal thickness

Perforated Specimen.



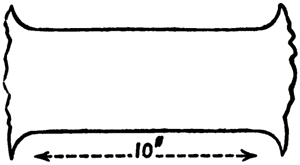
No. of Specimen.	Holes, how perforated.	Specimen if annealed.	Nominal Thickness.	Actual Thickness.	Width of Specimen.	Diameter of Holes.	Elongation of Holes at Ultimate Stress.	Net Sectional Area of Specimen.
1	2	3	4	5	6	7	8	9
			inch.	inch.	ins.	inch.	per cent.	sq. ins.
1	Punched -	Not annealed	1	0·99	6·66	1	3	4·61
6	Do. -	Do.	1	0·96	6·66	1	3	4·47
2	Do. -	Annealed -	1	0·97	6·66	1	22	4·52
5	Do. -	Do.	1	1·0	6·66	1	30	4·66
3	Punched small and bored to size.	Not annealed	1	1·0	6·66	1	25	4·66
4	Do. -	Do.	1	1·0	6·54	1	25	4·54
7	Drilled -	Do.	1	1·0	6·54	1	44	4·54
8	No holes -	Do.	1	0·99	4·66	Nil	—	4·61

TABLE 23.

STEEL COMPANY of SCOTLAND to ascertain the Effects (under Pulling Boring after Punching, and Drilling.

of Plate, 1 inch.

Unperforated Specimen.

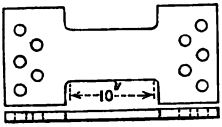


Total Stress. Ultimate.	Ultimate Stress per square inch of Gross Area.	Ultimate Stress per square inch between Holes.	Stress per Square Inch of Net Section compared with Solid Plate.	Contraction of Area at Fracture.	Extension Set in 10 Inches.		
					At 50,000 lbs. per square inch of Net Area.	At 60,000 Lbs. per square inch of Net Area.	Ultimate.
10	11	12	13	14	15	16	17
lbs. tons.	lbs. tons.	lbs. tons.	per cent.	per cent.	per cent.	per cent.	per cent.
225,500 100·66	34,218 15·27	48,915 21·83	77·4	4·33	Broken	Broken	0·8
207,312 92·55	32,443 14·48	46,378 20·70	73·4	6·48	Broken	Broken	0·7
293,040 130·82	45,362 20·25	64,831 28·94	102·7	24·55	0·9	2·8	6·9
305,984 136·6	45,943 20·51	65,661 29·31	104·0	24·89	2·3	5·4	9·1
315,616 140·9	47,389 21·15	67,728 30·23	107·3	18·02	1·8	5·4	7·9
285,600 127·50	43,669 19·49	62,907 28·08	99·6	13·87	1·8	4·9	7·2
289,138 129·07	44,210 19·73	63,686 28·43	100·9	33·25	2·3	5·1	12·0
290,976 129·90	63,118 28·17	63,118 28·17	—	38·82	4·7	12·8	29·0

TABLE 24.

RESULTS OF EXPERIMENTS made to ascertain the Effects upon counter-sunk right

Unperforated Specimen.

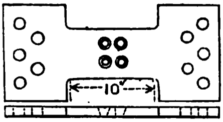


No. of Specimen.	Specimen.	Nominal thickness.	Actual thick-ness.	Width.	Diameter of Holes.		Elongation of small ends of Holes at Ultimate Stress.	Gross Sectional Area.
					Large end.	Small end.		
1	2	3	4	5	6	7	8	9
		inch.	inch.	inch.	inch.	inch.	per cent.	sq. in.
19	Punched and countersunk.	½	·507	6·375	·969	·750	33·33	3·232
20	Do. do.	½	·495	6·375	·969	·750	29·33	3·155
3	Drilled and countersunk.	½	·507	6·375	1·000	·755	37·33	3·232
4	Do. do.	½	·506	6·375	·995	·750	40·00	3·225
5	Unperforated -	½	·510	6·000	—	—	—	3·060
6	Do. -	½	·508	6·000	—	—	—	3·048
21	Punched and countersunk.	¾	·763	7·375	1·25	·875	25·71	5·627
22	Do. do.	¾	·748	7·375	1·21	·875	36·00	5·516
9	Drilled and countersunk.	¾	·75	7·406	1·25	·875	37·14	5·554
10	Do. do.	¾	·75	7·406	1·25	·875	36·00	5·584
11	Unperforated -	¾	·746	6·0	—	—	—	4·476
12	Do. -	¾	·752	6·0	—	—	—	4·512
23	Punched and countersunk.	1	·98	8·5	1·468	1	25·00	8·338
24	Do. do.	1	·96	8·5	1·468	1	22·00	8·168
15	Drilled and countersunk.	1	·97	8·5	1·468	1	28·00	8·245
16	Do. do.	1	·98	8·5	1·468	1	37·00	8·347
17	Unperforated -	1	·967	6·0	—	—	—	5·802
18	Do. -	1	·977	6·0	—	—	—	5·862

TABLE 24.

STEEL PLATES under Pulling Stress of Holes Punched and afterwards through the Plate.

Perforated Specimen.



Net Sectional Area.	Ultimate Stress.	Ultimate Stress per square inch of Gross Section.	*Ultimate Stress per square inch of Net Section.		Ultimate Stress per square inch of Net Section compared with the Solid Plate.	Contraction of Area at Fracture.	Ultimate Extension set in 10 Inches.
10	11	12	13		14	15	16
sq. in.	lbs. tons.	lbs. tons.	lbs. tons.	tons.	per cent.	per cent.	per cent.
2·35	145,600= 65·00	45,049=20·11	61,957=27·65	27·67	107	25.50	8·8
2·29	142,128= 63·45	45,048=20·11	62,064=27·7			25·82	8·7
2·34	141,456= 63·15	43,767=19·53	60,451=26·98	27·44	106	28·96	8·8
2·34	146,272= 65·30	45,355=20·24	62,509=27·9			30·31	10·0
3·06	174,048= 77·70	56,878=25·39	56,878=25·39	25·76	100	47·53	30·0
3·048	178,528= 79·70	58,572=26·14	58,572=26·14			47·86	31·0
4·00	255,696=114·15	45,440=20·28	63,924=28·53	28·82	108	17·41	7·5
3·95	257,600=115·00	46,700=20·84	65,215=29·11			20·35	8·0
3·96	260,848=116·45	46,965=20·96	65,870=29·4	29·20	109	21·72	10·0
3·96	257,376=114·90	46,091=20·57	64,993=29·01			22·94	10·0
4·476	268,800=120·00	60,053=26·8	60,053=26.8	26·65	100	37·6	27·5
4·512	268,016=119·65	59,400=26·51	59,400=26·51			46·33	28·5
5·91	387,968=173·20	46,530=20·77	65,646=29·3	29·53	108	15·65	7·5
5·79	386,176=172·40	47,279=21·1	66,697=29·77			16·88	7·0
5·85	377,888=168·70	45,832=20·46	64,596=28·83	29·22	107	14·0	9·0
5·91	392,000=175·00	46,962=20·96	66,328=29·61			21·72	11·0
5·802	354,928=158·45	61,173=27·3	61,173=27·3	27·28	100	48·30	30·0
5·862	358.064=159·85	61,082=27·26	61,082=27·26			47·85	30·6

* These results are obtained by deducting the mean diameter of the holes.

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Printers to the Queen's most Excellent Majesty.
For Her Majesty's Stationery Office.

Plate 1.

Fig. 1.

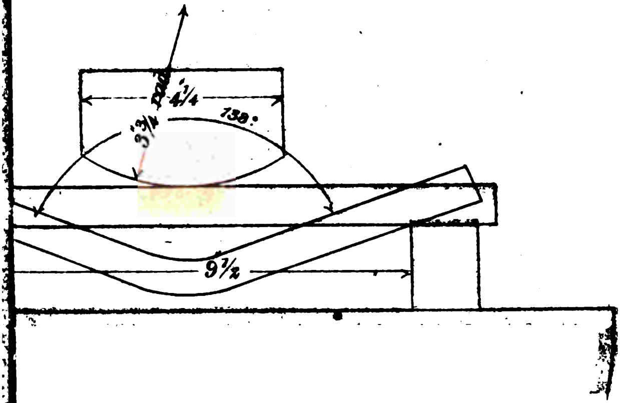
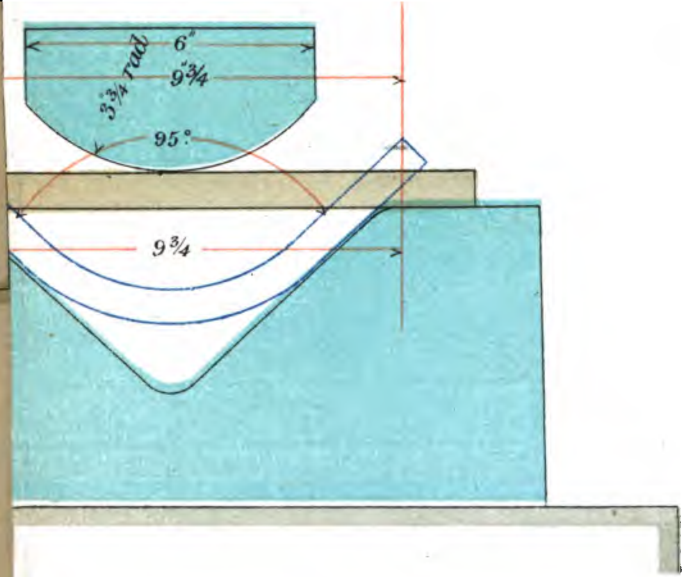
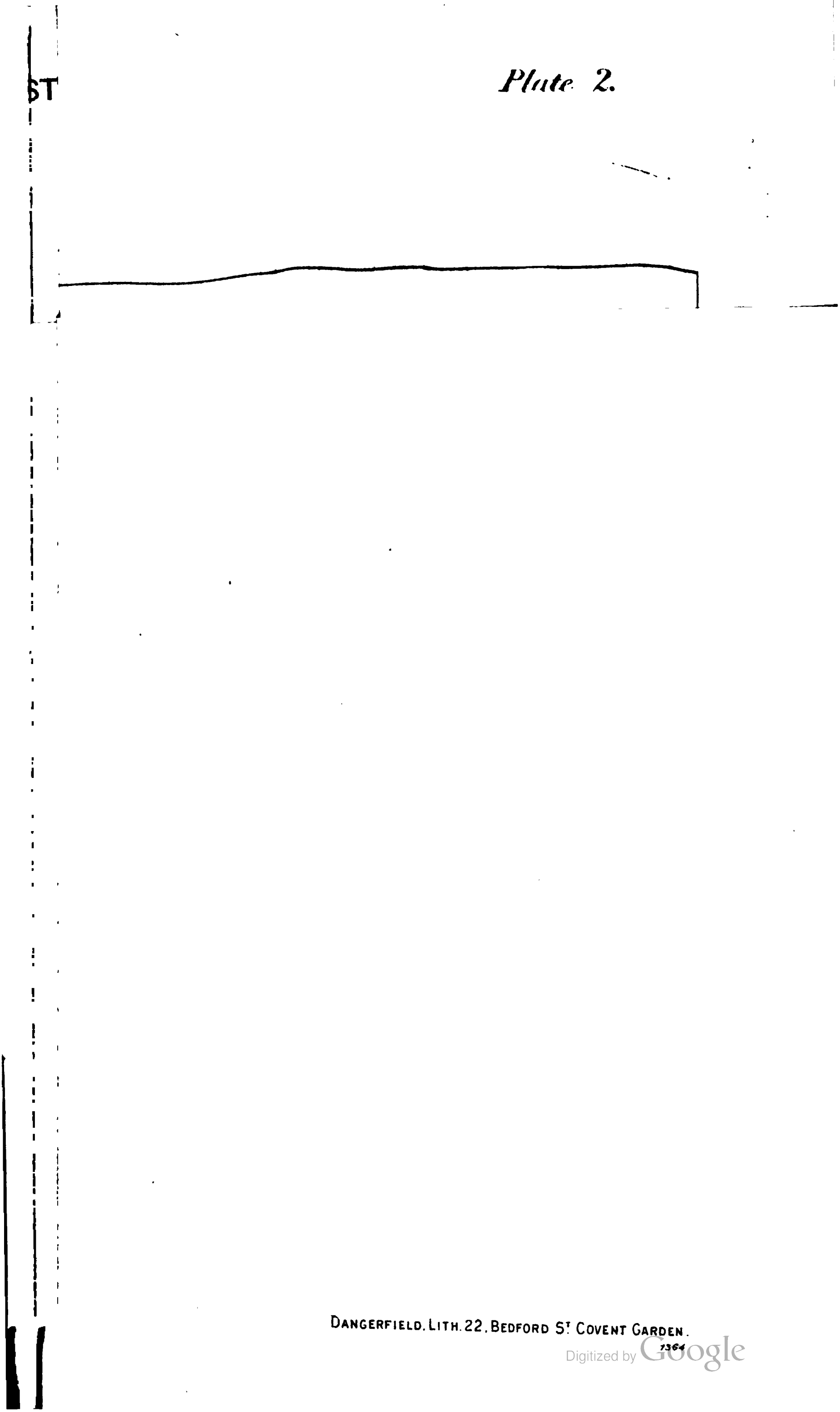


Fig. 2.



DANGERFIELD, LITH. 22, BEDFORD ST COVENT GARDEN
1364

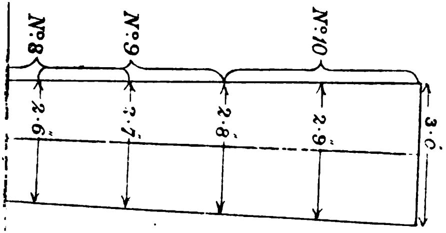
Plate 2.



Dangerfield. Lith. 22. Bedford St. Covent Garden.

1364

Plate 3.



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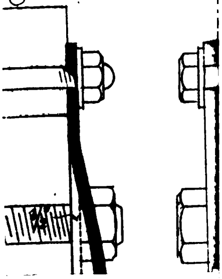

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MERCHANT SHIPPING STEAM SHIPS.

Memorandum issued by the Board of Trade for the use of their Surveyors, containing the Report of the Engineer Surveyor-in-Chief, and his Assistant, respecting the Experimental Bursting of the Boilers and Superheaters of the S.S. "Pharos."

Presented to both Houses of Parliament by Command of Her Majesty.

LONDON:
PRINTED BY GEORGE E. EYRE AND WILLIAM SPOTTISWOODE,
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.
FOR HER MAJESTY'S STATIONERY OFFICE.

1881.

[C.—2896.] *Price* 1s. 10*d*.

Report respecting the Experimental Bursting by Hydraulic Pressure of the Old Boilers and Superheaters of S.S. "Pharos."

Consultative Branch of Marine Department,
Board of Trade,
82, Basinghall Street, London, E.C.,
November 1st, 1880.

Sir,

Whilst at Hull, on duty in connexion with the work carried out on board S.S. "Pharos," I had the opportunity of witnessing the experimental bursting by water pressure of the old boilers and superheaters taken out of that vessel. Press of work has, up to the present time, prevented me from reporting upon the results obtained, which are of considerable value to engineers generally.

The experiments, which were carried out by Mr. Pratten and Mr. Seaton, engineer managers of Earle's Engineering and Shipbuilding Company, were witnessed by yourself, Mr. Spear, Surveyor of steam vessels at Hull, and other gentlemen.

The hydraulic pressures applied during the different experiments were registered by a standard high-pressure gauge, manufactured for the Board of Trade by Messrs. J. Dewrance and Company, London, and the indications were checked by a small duplex pressure gauge, such as is ordinarily used by the Board's surveyors, also by a gauge belonging to Messrs. Earle. The pressures recorded by the three gauges were found closely to agree on all occasions, and thus left no doubt respecting the accuracy of the pressures stated.

The donkey boiler, which was first experimented with, was about five years old, and had been worked at a pressure of 60 lbs. per square inch. It was of the ordinary vertical donkey boiler type, 4 feet 6 inches in diameter, with an upright circular fire box, 3 feet $8\frac{3}{8}$ inches mean diameter. The shell was originally $\frac{3}{8}$-inch thick, and the plates were lap-jointed with single rows of rivets spaced $2\frac{1}{8}$ inches apart. The longitudinal rows of rivets were continuous from end to end of the boiler. The shell plates had been reduced by corrosion at different parts to about $\frac{5}{16}$-inch, but at the laps they appeared to be the original thickness.

The fire box was, as regards circularity of shape, a very good specimen of fire boxes of this system of construction. It consisted of four plates joined together by single riveted lap joints. The plates were originally $\frac{3}{8}$-inch thick, but reduced to $\frac{11}{32}$-inch by corrosion.

At the root of the flange on the top of the fire box, where marked A on Fig. 1, considerable grooving had taken place; the thickness originally $\frac{1}{2}$-inch being reduced to $\frac{3}{16}$-inch. The part flanged up was reduced in thickness to $\frac{11}{32}$-inch, the reduction being no doubt to some extent due to the thinning effect of the operation of flanging. It will be seen by the drawing that there were no stays between the top of the boiler shell and the top of the fire box, such as are usually fitted, a fact which the result of the experiment showed to be worthy of note.

The hydraulic pressure was gradually applied to the donkey boiler. At 120 lbs. per square inch no alteration was observed in the firebox. The pressure having been gradually increased to 180 lbs. per square inch was then reduced to zero, when the fire box at one of the vertical riveted seams was found to be bulged inwards $\frac{3}{16}$-inch. A pressure of 200 lbs. per square inch was then applied, but owing to a leak at the bottom of the uptake, and at a lap at the bottom of the fire box the pressure dropped. It was then reduced to zero when the bulge of the fire box was found to be increased to $\frac{11}{32}$-inch. Upon the pressure being again applied after the leaky places were caulked the bulge increased to $2\frac{1}{4}$ inches, as shown by Figs. 1 and 2.

The fire box would, no doubt, have entirely collapsed had the pressure been continued, but as it was desired, if possible, to ascertain the ultimate strength of other parts of the boiler the pressure was lowered, and the fire box shored up with baulks of wood to prevent further distortion. The leaky places at the bottom, and at the base of the uptake were caulked, and the pressure was again applied to the boiler, but rather more rapidly than before; at 175 lbs. per square inch a sharp report was heard, and no further increase of pressure was obtainable owing to leakage, principally at the base of the uptake. As the pumping was continued the leakage at the latter place became very great and overpowered the pump, the pressure rapidly dropping; having been reduced to zero the seam at the base of the uptake was then very heavily caulked, and the pressure again applied. It rose to 100 lbs. per square inch, when violent leakage occurred at the same place and stopped the experiment. Upon opening the boiler it was found that the flange on top of the fire box to which the uptake was riveted had cracked through the rivet holes at B about half way round. During the experiment there was little or no leakage at the longitudinal seams of the boiler shell.

It has been stated that at a pressure of 180 lbs. per square inch a permanent set of $\frac{3}{16}$-inch was recorded, and that upon the application of an additional 20 lbs. per square inch the set increased to $\frac{11}{32}$-inch, and the pressure having dropped and been re-applied, the permanent set increased to $2\frac{1}{4}$ inches. It is thus clear that the collapsing pressure of the tube had been reached. It would indeed appear that, small as was the permanent set at 180 lbs. per square inch the fire box was then practically destroyed, and would probably have entirely collapsed at that pressure had it been continued for a short time.

The suddenness with which a slight distortion of the fire box was being followed by collapse, indicates clearly that the hydraulic test of circular tubes under external pressure, is not apart from the proper calculations a reliable guide that a sufficient margin of safety exists.

The experiments hitherto made to ascertain the resistance of tubes to collapse are not very numerous. Sir William Fairbairn carried out some experiments upon some small and thin tubes and deduced therefrom the following rule :—

$$\left.\begin{array}{r}\text{Collapsing pressure}\\ \text{per square inch}\end{array}\right\} = \frac{806{,}300 \times t^{2\cdot 19}}{L \times D}$$

where t = thickness of tube in inches
L = length in feet.
D = diameter in inches.

By the above rule :—

$$\text{Collapsing pressure} = \frac{806{,}300 \times (\frac{11}{32})^{2\cdot 19}}{3\cdot 2 \times 44\cdot 37} = 545 \text{ lbs. per sq. in.}$$

Taking the *actual* collapsing pressure as 200 lbs. per square inch, the calculated pressure by the above rule is thus very largely in excess of that obtained by the experiment.

In applying Sir William Fairbairn's rule, it has been usual with many engineers for the sake of simplicity of calculation to adopt the square of the thickness instead of the 2·19 power. The collapsing pressure of the fire box when calculated by the rule so modified $= \dfrac{806{,}300 \times (\frac{11}{32})^2}{3\cdot 2 \times 44\cdot 37} = 670$ lbs. per square inch which exceeds still more the actual collapsing pressure. This is quite in accordance with what has long been known by the advisers of the Board of Trade, viz., that almost immaterial as might at first seem the substitution of the square of the thickness for the 2·19 power, it causes a very considerable effect upon the results obtained, especially when the plates are very thin. It is found, in fact, upon examination of the results of Sir William Fairbairn's experiments, that if the square of the thickness be adopted in the rule given by him, the constant instead of being 806,300 should be 465,314.

Sir William Fairbairn, when giving his rule for the collapsing pressure of circular tubes, was aware of the necessity for them being perfectly cylindrical, and although he gave no special constant for use with tubes when made with lap joints, we find that he made an experiment with two tubes, one lap jointed and the other butt jointed, and found that the collapsing strength of the former was to that of the latter as 100 : 69·3 or 10 : 7 nearly. This result is very rarely referred to, the constant in the formula when quoted in the various text books being given for all tubes however constructed as 806,300 or thereabouts, unless when the length is expressed in inches, when it is multiplied by twelve.

The constant 465,314 when reduced in the above proportions becomes 322,462. The joints of the fire box of the donkey boiler were lapped and if we use the latter constant in Sir William Fairbairn's rule with the square of the thickness we have—

$$\left.\begin{array}{r}\text{Calculated collapsing}\\ \text{pressure of fire}\\ \text{box}\end{array}\right\} = \frac{322{,}462 \times \left(\frac{11}{32}\right)^2}{3\cdot 2 \times 44\cdot 37} = 268 \text{ lbs.}$$

per square inch, a result still in excess of the actual, but much more nearly correct than any of the calculated results already obtained. The discrepancy would show that the constant is still high.

It has been stated that the boiler had been worked at a pressure of 60 lbs. per square inch, so that at the time of the experiment the collapsing pressure of the tube was 3·3 times the working pressure. As the fire box plates had been reduced in thickness by corrosion there is no doubt that when the boiler was new the factor of safety was larger. We have seen the rapidity with which the fire box was failing after bulging was noted, so that the factor of safety of 3·3 can scarcely be considered sufficient, since with circular tubes under external pressure there is a liability to sudden failure almost as soon as an appreciable bulge is observed. In confirmation of this fact if any be wanted, it may be noted that in the memorandum of the Engineer Surveyor-in-Chief respecting some furnace tubes tested at Leeds, it is stated that a plain tube collapsed suddenly after a bulge of about $\frac{1}{16}$ inch was recorded.

Calculating the proper working pressure for the fire box by the usual Board of Trade rule for furnaces :—

$$\left.\begin{array}{r}\text{Working pressure}\\ \text{per square inch}\end{array}\right\} = \frac{C \times (t)^2}{(L+1) \times D}$$

When D = diameter in inches
L = length in feet.
t = thickness in inches.
C = 70,000 the constant appropriate to the description of joint.

$$\text{Working pressure} = \frac{70{,}000 \times \left(\frac{11}{32}\right)^2}{(3\cdot 2 + 1) \times 44\cdot 37} = 44 \text{ lbs. per square inch.}$$

The pressure which would be allowed by the Board's surveyors allows therefore a factor of safety 4·5, not by any means too much when it is considered how much the strength of such a part of the boiler may be reduced by an accidental or unobserved inaccuracy in the circularity of the tube, arising either from defective workmanship or from over-heating caused by the presence of dirt or shortness of water.

It has been stated that after the boiler was subjected to a pressure of 200 lbs. per square inch, the fire box was shored up with baulks of wood to prevent further distortion, and upon pressure being again applied the flange at the top of the fire box riveted to the uptake gave way at 170 lbs. per square inch by the cracking of the plate between the rivet holes. It would thus appear that although this part had borne the strain arising from the higher pressure of 200 lbs. per square inch, that the material must have been injured thereby, and consequently failed at a lower strain. The fact is worthy of notice as bearing upon the injurious effects liable to arise from over-testing of materials or structures.

The failure of the boiler at the flange of the fire box is interesting, owing to the fact that unlike many other boilers of the same class there were no stays fitted to assist the uptake in supporting the tops of the boiler and fire box. The top was dished to form part of a sphere 11 feet 4 inches diameter, and was $\frac{7}{16}$ inch thick. Assuming the tensile strength of the iron to be 47,000 lbs. per square inch, the bursting pressure of a sphere of the above dimensions is 604 lbs. per square inch. Although this is very much greater than the pressure applied to the boiler, it was very evident by the increased convexity under pressure of the dished top of the shell, between the uptake and the outside shell, that a considerable stress was borne by the uptake, and consequently the part of the fire box to which it was attached.

Let the stress upon the latter part where fracture occurred be calculated upon the assumption that it sustained the pressure upon that portion of the dished top which is enclosed by the circle midway between the uptake and the shell. We find that under these circumstances with a pressure of 170 lbs. per square inch on the boiler, the metal between the rivet holes of the flange of the fire box, where fracture occurred, gave way at a stress of only about 6¾ tons per square inch. As this is only about one-third of the tensile strength of good wrought iron it is evident either that the uptake should be credited with sustaining a larger portion of the pressure on the dished top than has been assumed, or the material where fracture occurred had been injured by the operation of flanging. Upon either hypothesis it is evident that stays should be fitted between the top of the boiler, and the top of the fire box.

The necessity for the fitting of the stays is increased by the liability of the uptakes of donkey boilers to get over-heated. In case of shortness of water to which these boilers are specially liable from the inefficient character of the attendance they frequently receive, the sufficiency of the uptake as a stay is still further impaired by its base and the flange of the top of the fire box, which are weakened by rivet holes, being liable to become over-heated.

The experience of the Board's surveyors is conclusive as regards the serious effects of over-heating upon the uptakes of donkey boilers. The officers of Boiler Insurance Companies have evidently similar experience, for we find that the Chief Engineer of one of them frequently in his annual reports recommends the insertion inside the uptake of a loose sleeve of cast iron, or other suitable material, in order to save the uptake plates from becoming red hot.

Although the uptake ultimately gave way at 170 lbs. per square inch, its liability to become over-heated prevents us from regarding the experiment as a proof that the boiler would, under the ordinary conditions of working with steam up, withstand a pressure approaching it. A very considerable reduction from it must be made owing to the weakening effect of the high temperature to which the uptake is raised. In the absence of experiments on the subject it is of course impossible to state definitely the exact degree of over-heating which occurs, but considering the frequency with which flames issue from the funnels of these boilers, and the low conductivity of the steam, there can be little doubt that they are frequently red hot, or nearly so, a fact which receives proof from their condition.

The experiments of the Board's officers have shown that the tensile strength of red-hot iron plates is only about one fourth of that when cold. The uptake therefore which gave way at 170 lbs. per square inch when cold, cannot under the ordinary conditions of working be depended upon for pressures at all approaching it. It is in fact evident that a donkey boiler, not fitted with stays between the top of the boiler and the top of the fire box, may often be working with a very narrow margin of safety. The plan referred to of a protecting tube in the uptake is no doubt a good one, but under general circumstances safety is assured by the fitting of stays to reduce the tensile stress on the uptake.

The after main boiler which was also tested to ascertain its Ultimate strength was of the ordinary Marine type fired from one end and fitted with three furnaces, each having a separate combustion chamber. The general arrangement is shown in Figs. 3 and 4. The shell of the boiler was 13 feet diameter, 9 feet $9\frac{3}{4}$ inches long over the end plates and was originally $\frac{7}{8}$-inch thick, but was reduced at the riveted seams to $\frac{27}{32}$-inch. The longitudinal seams were lap jointed with three rows of rivets arranged zig-zag, the rivets, which were $1\frac{1}{16}$-inch diameter, were spaced $3\frac{1}{2}$ inches apart, and the perpendicular distance between the adjacent rows was $1\frac{7}{8}$-inches. The circular seams were lap jointed and double riveted.

The furnaces were 3 feet 1 inch diameter, $\frac{17}{32}$-inch thick, and 6 feet 6 inches long, the length of the bottom plates, including the fire box plate, being 9 feet. Each furnace was constructed of two plates united by a double riveted lap joint beneath the furnace bars, the bottom plate of each furnace being in a line with the bottom of the fire box. An angle iron was riveted at the bottom immediately under the back tube plate, the object evidently being to render the whole of the furnace, for purpose of resistance to collapse, of the same strength as the top plate; such at least is the avowed intention in similar cases. The angle iron, however, fitted in a manner not unusual, was, as will be seen by Fig. 3 insufficient in length to stiffen the plate to the same extent as a ring round it would do, a large space at each side being left unstiffened, and was thus apparently the weakest part of the furnace.

In order to ascertain the elongation of the shell of the boiler whilst under pressure a steel wire was stretched over half the circumference, being kept tight by a weight at each end. A mark was made on the wire on each side at the half circumference, and a similar mark was made on the shell of the boiler, both being coincident prior to the application of the pressure. The sum of the distances between the marks on wire, and boiler on both sides, during and after the application of pressure represented the elongation and permanent set respectively of the boiler shell in the half circumference. It had been suggested to encircle the entire circumference of the boiler with the wire, but in similar experiments in which the plan had been adopted, the wire had broken owing to the strain arising from the friction between it and the boiler. Even had it not broken, the friction would have caused an extension of it, and consequently incorrect results would have been given. By encircling only half the circumference, and having the surfaces well oiled, the friction was very much reduced, and the extension of the wire, it is believed, prevented. It should be stated that prior to my arrival at the Works, the Manager had, in order to test the tightness of the joints, subjected the boiler to a pressure of 200 lbs. per square inch, so that the extension observed must be considered as affected by the boiler having been previously subjected to so high a pressure.

In carrying out the experiment the hydraulic pressure was slowly applied. As it approached 200 lbs. per square inch cracking sounds were heard from inside the boiler, and the longitudinal seams began to leak slightly. The leakage increased as the pressure rose, until at 230 lbs. per square inch the boiler leaked so much, principally at the longitudinal seams, that the pressure could not be got higher, although it was maintained for some time at that pressure. The experiment was therefore stopped in order to caulk the joints. Upon the conclusion of this part of the experiment, it was found that there was in the half circumference a permanent extension set of $\frac{3}{32}$-inch. The joints having been caulked, the pressure was slowly re-applied as before, until at 200 lbs. per square inch the longitudinal seams began to leak. Cracking was heard from inside the boiler as the pressure rose from 220 lbs. to 240 lbs., the leakage increasing at the longitudinal seams, but not so rapidly as before. At 260 lbs. the centre furnace *collapsed* as shown in the drawing, Figs. 3 and 5, a slight fracture occurring in the plate at the top of the back end of the furnace. The pressure then rapidly fell, and consequently the collapse of the furnace was not complete as it would have been if steam instead of water pressure had been used.

The wires encircling the half of the boiler indicated that there was an additional extension set in half the circumference over what had been previously recorded of $\frac{3}{32}$-inch, making a total extension set in the same length of $\frac{3}{16}$-inch, to which should be added the set which no doubt occurred at the first test by the Manager, but which was not measured.

Although the longitudinal joints of the shell leaked very badly and gaped considerably, no fractures were observable from the exterior at the time of the experiment, but subsequently, when breaking up the boiler, Mr. Seaton informed me that some cracks were discovered between the rivet holes at the longitudinal seams. The plate was, I have been informed, put aside for my inspection, but unfortunately having been accidentally destroyed, I did not see it.

In cases of boiler shells which have been burst experimentally it has been found that entire failure occurs as soon as a slight fracture takes place at the weakest place, whether this be a riveted seam or any other part. As cracking was beginning at a longitudinal seam, it is evident that the boiler shell was upon the point of bursting.

If in the calculation for the bursting pressure we assume the tensile strength of the plate to be equal to 47,000 lbs. per square inch, and neglect the injurious effects of punching and lap-jointing, we have—

$$\left.\begin{array}{c}\text{Calculated bursting}\\ \text{pressure}\end{array}\right\} = \frac{47{,}000 \times \cdot 69 \times 2 \times \frac{27}{32}}{156} = 350 \text{ lbs. per}$$

square inch. This is the calculated bursting pressure of a boiler made with double-butt straps, and with the holes drilled. According to the Board's rules a deduction should be made therefrom, in the case of the boiler in question, of 16·6 per cent., corresponding to the additions to the factor of safety of D. I. K. S. Deducting 16·6 per cent. from 350 lbs., we have the calculated bursting pressure of the boiler by the Board's rules as 292 lbs. per square inch. The pressure actually applied was 260 lbs., or only about 10 per cent. less.

It will be observed by the drawing that the collapse of the furnace occurred neither at the top nor bottom, but at the upper part of one of the sides, which have been referred to as apparently the weakest parts of the furnace, owing to them being unstiffened from back to front. It is noteworthy that the opposite side of the centre furnace was bulged inwards slightly at a similar part. The fitting of a short angle iron under the bottom of a furnace does not, it is evident, like a continuous ring, effectually stiffen the adjacent parts over which it does not extend circumferentially. It would appear that some apology is required for making a remark so exceedingly obvious, but the plan of fitting these short angle irons for the purpose of stiffening furnace tubes is so common, that there has been a difficulty in convincing some persons that the plan is insufficient for the purpose. This plan is sometimes adopted when the bottom furnace plates are too thin, owing to a natural indisposition to allow the angle iron to extend as high as the furnace bars; but the primary necessity of ensuring the cylindrical form of the furnace by a stiff ring entirely encircling it, or by some other adequate means, is, it is thought, enforced by the results of the experiment on this boiler.

The necessity for the ring round furnace tubes being ***continuous*** was forcibly shown by an experiment recently carried out. A land boiler with a long tube, having one stiffening ring near the centre, was being tested to destruction when the tube was found to collapse most severely at the stiffening ring, instead of midway between the ring and either end. Upon examination it was discovered that the ring, which was in parts, had not been fitted with straps to make it continuous.

Referring again to the "Pharos" main boiler;—according to the Board of Trade rules the working pressure which would be allowed for a furnace the same length as the bottom plate, including the length of the fire box—

$$= \frac{80{,}000 \times \left(\frac{17}{32}\right)^2}{(9 + 1) \times 37} = 61 \text{ lbs. per square inch.}$$

The pressure at which the boiler was worked was 60 lbs. per square inch, so that the factor of safety possessed by the furnace is $\frac{260}{61} = 4 \cdot 2$, not by any means too great. Calculating the collapsing pressure of the furnace, by the rule given by Sir William Fairbairn, already referred to, we have—

$$\text{Collapsing pressure} = \frac{806{,}300 \times \left(\frac{17}{32}\right)^{2 \cdot 19}}{9 \times 37} = 605 \text{ lbs. per square}$$

inch. This pressure is 132 per cent. in excess of the pressure at which the furnace actually collapsed.

If, instead of using the 2·19 power of the thickness in the above formula, the square of the thickness is adopted as is ordinarily done by some engineers, we have—

$$\text{Collapsing pressure} = \frac{806{,}300 \times \left(\frac{17}{32}\right)^2}{9 \times 37} = 683 \text{ lbs. per square}$$

inch. The result is considerably greater than the former, and is, 162 per cent. in excess of the actual collapsing pressure of the furnace. Both formulæ are, it is seen, very far from giving results at all agreeing with the actual one.

When considering the experiment with the donkey boiler, reference was made to the fact that the constant obtainable from Fairbairn's experiments, when the square of the thickness is adopted, instead of being 806,300, is really 465,314; also that by two of the experiments it was found that the resistance to collapse of a butt-jointed tube was to that of one lap-jointed as 100 : 69·3 and that therefore for lap-jointed tubes the constant in the formula should be reduced to 322,462. By the use of this constant we have—

$$\text{Collapsing pressure} = \frac{322{,}462 \times \left(\frac{17}{32}\right)^2}{9 \times 37} = 273 \text{ lbs. per square}$$

inch. The actual collapsing pressure was 260 lbs. per square inch, so that by Fairbairn's rule, with *altered* constant, we get a result only five per cent. in excess of it, instead of 132 per cent., and 162 per cent. in excess, as obtained by his rules as ordinarily adopted.

The tubes we have hitherto dealt with were lap jointed. We have, however, the means of testing the suitability of Fairbairn's rule for ascertaining the resistance to collapse of full-size furnaces with *welded* joints, in the case of a furnace tested at Greenock by the Greenock Foundry Company in 1877, and also one tested at Leeds in 1878 by the Leeds Forge Company in the presence of Mr. Traill, Engineer Surveyor-in-Chief to the Board of Trade. The particulars are included in the annexed tabulated form.

The results are reported of an experiment made by the Engineer-in-Chief of the United States Navy on a large furnace tube 4 feet 6 inches diameter, 6 feet long, and ¼-inch thick. It consisted of two tubes, each 3 feet long, joined by flanges, the longitudinal joints being made with butt straps and double riveted. When subjected to a pressure of 100 lbs. per square inch, one length began to bulge. The bulge was then shored up and new ones began to form in the same part of the tube at 130 lbs. These were shored up and the other part of the tube began to collapse at 128 lbs. per square inch. It is probable that the previous bulge at 100 lbs. was due to a slight inaccuracy in the tube and that therefore 128 lbs. per square inch may fairly be considered its collapsing pressure. A comparison of the calculated pressure with the actual is given in the table annexed.

			Calculated Collapsing Pressure per Square Inch of Furnace Tubes by									
	Dimensions of Furnace Tubes.	Description of Longitudinal Joints.	Fairbairn's Rule No. 1. $\frac{806300 \times t^{2 \cdot 19}}{L \times D}$	Fairbairn's Rule No. 2. $\frac{806300 \times t^2}{L \times D}$	$\frac{465314 \times t^2}{L \times D}$	Rule for Lap-jointed Tubes. $\frac{322462 \times t^2}{L \times D}$	Actual Collapsing Pressure per Sq. Inch.	Calculated Pressure in Columns 6 or 7 greater or less than actual Collapsing Pressure.	Calculated Pressure by Fairbairn's Rule, Column 4, greater or less than actual Collapsing Pressure.	Calculated Pressure by Fairbairn's Rule, Column 5, greater or less than Actual Collapsing Pressure.	Working Pressure allowed by Board of Trade Rule.	Factor of Safety with Working Pressure by Board of Trade Rule.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
	′ ″		lbs	lbs.	lbs.	lbs.	lbs.				lbs.	
Fire box of donkey boiler, S.S. "Pharos." - -	Mean diam. 3 8⅜ Length 3 2½ Thickness 0 0$\frac{11}{32}$	Lap	545	670	—	268	200	34 % greater.	172 % greater.	235 % greater.	44	4·5
Furnace of main boiler, S.S. "Pharos." - -	Diameter 3 1 Length - 9 0 Thickness 0 0$\frac{17}{32}$	Lap	605	683	—	273	260	5 % greater.	132 % greater.	162 % greater.	61	4·2
Furnace tube tested at Greenock -	Diameter 3 2 Length 7 2 Thickness 0 0½	Welded	648	740	427	—	450	5 % less	44 % greater.	64 % greater.	72·5	6·2
Furnace tube tested at Leeds - -	Diameter 3 2 Length 7 0 Thickness 0 0⅜	Welded	351	426	246	—	187·5	31 % greater.	87 % greater.	127 % greater.	41·6	4·5
Furnace tube tested by the Engineer-in-Chief, United States Navy - -	Diameter 4 6 Length 6 0 Two lengths of 3 feet joined by flanges. Thickness 0 0¼	Butt	239	311	179	—	128	39 % greater.	86 % greater.	142 % greater.	26	4·9

In the case of the furnace tube tested at Leeds the collapse was believed to have taken place at a lower pressure than it otherwise would have done, owing to the presence of a bulge of about ¼-inch in depth where the collapse began. This may account for the pressure borne by this tube being proportionally so much lower than that tested at Greenock.

Comparing the figures in column 9 with those in columns 10 and 11 we see that whilst Fairbairn's rule as ordinarily adopted gives very inaccurate results, those obtained by the formulæ at the heads of columns 6 and 7 are much more nearly accurate. The greatest divergence from the actual results obtained by experiment, occurs with the largest and thinnest tubes in which a slight deviation from the circular form is obviously most prejudicial. As the calculated pressures are in all cases but one in excess of the actual, the constants if further modified should evidently be reduced.

With the pressure which would be allowed by the Board's rules for these furnaces there is a mean factor of safety of 4·8, which must be considered as very moderate considering how much the strength of a tube under external pressure is reduced when slightly out of the circular form.

A formula used by some engineers for ascertaining the working pressure to be allowed for the furnaces of Marine boilers is as follows :—

$$\text{Working Pressure} = \frac{89600 \times t^2}{L \times D}.$$

where *t*, L and D represent the same as before.

The above would appear to be intended to allow one-ninth of the pressure obtained by Fairbairn's formula :—

$$\text{Collapsing pressure per sq. inch} = \frac{806{,}300 + t^2}{L \times D}.$$

As that rule with the five furnace tubes in the tabulated form gives results 235, 162, 64, 127, and 142 per cent. in excess of those actually obtained, it is obvious that it is an unreliable guide for ascertaining the proper working pressure. The factor of safety with the working pressure obtained by the above rule, instead of being 9, as might appear to be the case to some persons is respectively only 2·6, 3·4, 5·4, 4·0 and 3·7 in the five cases given on the tabulated form. The rule, as might be anticipated from the results previously given, is most inaccurate with the tubes constructed with lap joints.

The facts given clearly show that Sir William Fairbairn's rule for the collapsing pressure of short circular tubes is (with the constant reduced) much more reliable than when used with that ordinarily adopted. Also that with the pressure allowed by the Board of Trade rules for the furnaces of Marine boilers only a very moderate factor of safety is obtained. A larger number of experiments may possibly give greater emphasis to these facts. In order that further information respecting this important subject may be obtained it is much to be wished that the owners of old boilers could be induced when they are disused to submit them to bursting pressure.

It is not suggested that the particulars given will enable an opinion to be formed respecting the applicability of Sir William Fairbairn's rule to furnaces of extreme length, such as are sometimes found in land boilers. It is quite intelligible that the same rule for collapsing pressure may not apply to short tubes and to those of great length.

The influence of the ends of the boilers in retaining the tubes in a circular form can scarcely be effective beyond a certain distance from each end. When this is reached, it would appear that any further increase in length is not so potential as formerly in reducing the resistance to collapse. According to the usual rule a very long tube should withstand practically no pressure, whereas it is obvious that even if indefinitely long it would by virtue of its circular form, and acting as an arch, be capable of considerable resistance to collapse, just as a short tube without any end attachments.

Very few, if any, reliable experiments have been made on full size long furnace tube, notwithstanding that precise information respecting their strength is most *urgently* needed. The experiments of Sir William Fairbairn were made on small and thin tubes differing in dimensions so widely from the full size furnace tubes to which his rules are applied, that they cannot be considered as quite sufficient.

The testing of the forward main boiler was next proceeded with, the same means being adopted as during the experiment on the after main boiler in order to ascertain the extension of the cylindrical part of the shell. The hydraulic pressure was slowly applied. At 180 lbs. per square inch the longitudinal joints of the shell began to leak. At 200 lbs. they leaked more freely, and the manhole door leaked badly, necessitating the re-making of its joint. The following were the elongations in the circular part of the shell in half the circumference during the above experiment:—

Pressure per square inch.	Elongation under pressure.
lbs.	inch.
120	nil.
180	$\frac{1}{16}$
200	$\frac{1}{8}$

The wire for recording the extensions was accidentally removed during the re-making of the manhole door joint, so that upon the subsequent application of pressure, the further extensions recorded were taken from fresh marks, and must be added to the above. Upon the gradual re-application of the pressure it was found that leakage at the longitudinal seams occurred at a lower stress than during the previous test, viz., at 160 lbs. per square inch. At 180 lbs. the leak increased. At 210 lbs. leakage became greater from the longitudinal seams and from a seam at the top of the fire box. A larger pump was then connected. At 230 lbs. a sharp report was heard. At 235 lbs. the pump rod broke, and the pressure fell to zero. After a new rod was fitted pumping was again commenced, and a pressure of 250 lbs. was applied, but the leak overpowered the pump. The longitudinal seams were then heavily caulked and the pressure again applied. At 250 lbs. per square inch a loud report was heard and there was considerable leakage at the longitudinal seams. The pressure was kept on for about 15 minutes, after which it dropped, owing to the increase in the leakage at the longitudinal seams and at a riveted seam at the top of the fire box. Upon examining the shell of the boiler a slight crack was found at the lap of one of the circular riveted seams in line with a longitudinal seam. The experiment was again continued, and the pressure rose to 260 lbs. per square inch, but the leakage increasing overpowered the pump after a few minutes, and the experiment was discontinued and was not again resumed, as the pumping power at disposal was insufficient to overcome the leakage.

The following are the elongations and permanent sets observed in half of the circumference of the circular part of the shell during the second part of the experiment:—

Pressure per Square Inch.	Elongation under Pressure.	Permanent Extension set with Pressure removed.
lbs.	inch.	inch.
160	$\frac{3}{32}$	Not taken.
180	$\frac{1}{8}$ bare.	„
210	$\frac{1}{8}$ full.	„
235	$\frac{3}{16}$ „	$\frac{3}{32}$
255	$\frac{1}{4}$ „	$\frac{1}{8}$ bare.
260	Not taken.	Not taken.

The extensions given in column 2 are in addition to those recorded previously.

It is not unfrequently suggested that the working pressure to be allowed upon a steam boiler may, irrespective of calculations of strength, be regulated by the pressure which it will bear without visible distortion or distress. The result of this experiment shows that very considerable difficulty would be experienced in carrying out this plan, and that there would be great danger of overstraining the boiler. When a circular boiler is tested the extension, if any, is almost wholly confined to the lines of weakness at the rivet holes, and consequently would be considerably influenced by the number of such lines of weakness, and in fact depend to some extent upon whether the boiler was made with long or short plates. The amount of extension would also depend upon the hardness or softness of the material. Such variable conditions, apart from the difficulty in deciding when the point of undue strain was reached, and apart from other considerations, would render the carrying out of the plan a matter of extreme difficulty, and in some cases cause the boiler to be overstrained. The danger of working a boiler that had been so treated is obvious without further comment.

The leakage at the seam at the top of the fire box was caused by the straining of the seam, owing to the girders to which the stays on top were fitted not being immediately over the tube plate and back of combustion box, but partly resting upon the horizontal plates.

With the exception of the crack in the shell already referred to, no fracture was observed in the circular part of the shell, but the pressure applied being identical with that which caused cracks at the longitudinal seams of the other main boiler it is evident that the bursting pressure was very closely approached. The severely strained condition of the shell plates was also shown by the centre of the belts of plates at the longitudinal seams being bulged outwards about $\frac{1}{8}$-inch in a length of 2 feet 10 inches.

It will be remembered that in the other main boiler the centre furnace collapsed at a pressure of 260 lbs. per square inch. In this boiler, however, the furnaces, although similar, showed no signs of collapse. The fact is instructive, as showing how closely the collapsing pressure of a tube may be approached without appreciable signs of collapse being given, and is only another warning added to many others against making the test by water pressure, irrespective of calculation, a criterion of the strength of such parts of steam boilers.

The forward superheater was next tested. It consisted of an external circular shell with an internal tube at the centre extending from end to end, through which the products of combustion passed to the funnel. The external part was thus subject only to the heat of the steam, and was consequently as regards the effects of heat under not worse conditions than the shells of the boilers.

The external shell was 6 feet 6 inches diameter inside, 5 feet 7 inches long, and $\frac{1}{2}$-inch thick. The plates at the longitudinal joints were lapped and riveted with two rows of $\frac{13}{16}$-inch rivets spaced $2\frac{5}{8}$ inches apart, and the circular seams were lap-jointed with a single row of rivets spaced $2\frac{1}{8}$ inches apart.

The internal tube was 4 feet diameter externally, and the plates which were $\frac{1}{2}$-inch thick were lap-jointed. The tube was strengthened to resist collapse by means of two angle irons 3-in. × 3-in. × $\frac{1}{2}$-in., and so placed as to divide the length roughly into three parts. The principal part of the plates, originally forming the inner tube of the superheater, had been so much wasted by corrosion that they had been cut out and replaced by others about fifteen months before the boilers were removed from the ship. Those fitted in place of them, which were of Lowmoor iron, were not much affected by wear, having, I believe, been protected by baffle plates. The end plates, which were $\frac{9}{16}$-inch thick, were stiffened by angle irons 3-in. × 3-in. × $\frac{1}{2}$-in., extending from the inner tube to the outer shell and spaced about 13 inches apart.

The manhole, which was $16\frac{3}{8}$-in. × $11\frac{3}{4}$-in., was strengthened by a ring 3-in. × $\frac{3}{4}$-in., riveted round it. There were three other holes in the shell 7 inches in diameter, which were unstrengthened. Round one of them, which is shown in figure 9, a second row of bolt holes had been drilled in error and afterwards filled up.

The extension of the cylindrical shell under pressure was ascertained as in the previous experiments, by means of a small steel wire stretched half way round at the centre of a belt of plating.

The hydraulic pressure was gradually applied until it rose to 120 lbs. per square inch when the extension in half the circumference was barely $\frac{1}{16}$-inch. Upon the pressure being allowed to drop to zero it was found that there was in the same length a permanent set of barely $\frac{1}{32}$-inch. The pressure was again applied, and at 205 lbs. per square inch one of the longitudinal riveted joints began to leak, and as the pressure rose leakage occurred at the other joints of the same description. At 260 lbs. the longitudinal joints were strained so much that at the laps at the centres of the belts of plating the blade of a penknife could be inserted some distance. At 280 lbs. per square inch a loud knock was heard, and the leakage increased so much that the pressure dropped. Pumping was then continued more rapidly than before and the pressure again rose to 280 lbs., but the leakage at the longitudinal joints and at a blank flange at a steam pipe orifice again increased so much that the pressure again dropped. The experiment was then stopped in order to obtain greater pumping power. As the bulging of the plate at a steam pipe orifice arrested attention, the blank flange was removed, and the *plate* was found to be *cracked* as shown in figure 9.

The shell at the other 7-inch holes was also considerably strained, the plate at the parts of the holes nearest the ends of the superheater being much bulged out. The shell at the manhole was also strained, and appeared to indicate that a heavier strengthening ring would have been required in order to make up entirely for the loss of strength arising from the plate cut away.

The following are the elongations and permanent sets observed in half the circumference of the superheater shell :—

Pressure per Square Inch.	Elongation under Pressure.	Permanent set with Pressure removed.
lbs.	inch.	inch.
120	$\frac{1}{16}$ bare	$\frac{1}{32}$ bare
160	$\frac{1}{16}$ full	Not taken
200	$\frac{1}{8}$,,	,,
230	$\frac{3}{16}$	,,
260	$\frac{1}{4}$	,,
280	Not taken	$\frac{1}{8}$

The permanent sets were not taken after the application of the pressures intermediate between 120 lbs. and 280 lbs. per square inch, owing to the difficulty experienced through leakage.

That the fracture of the plate at the steam pipe orifice did not extend further, is possibly to be attributed to the fact that in order to prevent the studs by which the blank flange was secured from giving way under the hydraulic pressure, an additional plate had been put inside the superheater, the inside and outside plates being secured together by a large bolt passing through both. Had the hole been fitted merely with an ordinary manhole door inside, there can be no doubt that it would have blown right out when the plate cracked.

Adopting 47,000 lbs. as the tensile strength per square inch of the plates of the superheater shell we have :—

$$\left.\begin{array}{r}\text{Calculated bursting pressure}\\ \text{through the } \textit{solid} \text{ plate } -\end{array}\right\} = \frac{47{,}000 \times 2 \times \frac{1}{2}}{78} = 602 \text{ lbs. per}$$

square inch.

The pressure which fractured the plate at the steam pipe orifice was only 280 lbs. per square inch, the strength of the superheater shell at that part was therefore only 46 per cent. of the strength through the solid plate, *the presence of the hole causing a loss of strength of* 54 *per cent.*

Mr. Lavington Fletcher, Chief Engineer of the Manchester Steam Users Association, tested to destruction a boiler 7 feet diameter and $\frac{7}{16}$-inch thick having an unstrengthened manhole measuring 17 inches × 13 inches. The shell fractured at the manhole at a pressure of 200 lbs. per square inch, and the door was blown right out. The actual strength at the manhole was only 40 per cent. of the calculated strength of the boiler through the solid plate, the loss of strength thus being 60 per cent. The reduction of strength of the superheater shell was rather less than in the boiler referred to, but the conditions as regards size of hole and diameter of boiler were more unfavourable in Mr. Fletcher's experimental boiler than in the superheater shell.

The weakness of a circular shell in the vicinity of a hole cut therein when subject to internal pressure, is clearly due to the fact that the plates at the sides of the hole not only sustain the stress due to the pressure on half the diameter of the belts of plating of which they form parts, but also the stress due to the pressure acting upon an area equal to the size of the hole measured lengthway of the boiler multiplied by half the diameter of the boiler. At the pressure of 280 lbs. per square inch the additional strain at each side of the steam pipe orifice of the Superheater shell caused by the metal being cut away—

$$= \frac{7}{2} \times \frac{78}{2} \times 280 = 38{,}220 \text{ lbs. or } 17 \text{ tons.}$$

If the additional stress arising from the plate cut away at a steam pipe orifice, or manhole, were spread over the whole section of metal in the shell under strain, but little weakness would result from it, but being localised at the sides of the hole the metal there gives way and the plate tears across.

The presence of the additional row of bolt holes round the steam pipe orifice where fracture occurred may have somewhat affected the strength of the superheater, but not, it is thought, to any material extent, considering the degree of straining which was found to have occurred at the other steam pipe orifices in which only one row of holes was drilled in the usual way.

The experience afforded by disastrous boiler explosions arising from unstrengthened manholes has had a salutary effect in causing engineers to have such parts strengthened, but the weakness arising from steam pipe orifices, and the necks of steam chests and superheaters, the latter, sometimes 16 inches diameter, are very frequently overlooked, and when recognised most inadequately provided for. When such is pointed out in the case of the necks of steam receivers, it is not unfrequently suggested that the neck with its flange affords a considerable amount of strength to the opening. In such cases the neck is rarely thicker than the boiler shell, and is most frequently much thinner.

We are indebted to Mr. Lavington Fletcher for a valuable experiment bearing on this subject. A neck $15\frac{3}{8}$ inches internal diameter, $11\frac{3}{4}$-inches high, and $\frac{7}{16}$-inch thick was single riveted to a boiler shell 7 feet diameter and $\frac{7}{16}$-inch thick. When tested to destruction the plate at the base of the neck cracked at a pressure of 250 lbs. per square inch or at a stress only 50 per cent. of the ultimate stress of the solid plate. Comparing this result with that obtained by Mr. Fletcher with the unstrengthened manhole, it will be seen that the strength afforded by the neck to the boiler shell at the hole was comparatively small.

The after superheater which was next tested was similar in design and dimensions to the forward one.

The pressure was slowly applied until it rose to 200 lbs. per square inch, when the longitudinal seams began to leak, and the joints to gape slightly. As the pressure continued to rise the leakage and the gaping of the laps of the joints increased. When 310 lbs. per square inch was reached it remained stationary for about 10 minutes, when some leaky places having been caulked, the pressure rose to 325 lbs. per square inch. This was kept up for 10 minutes when the superheater shell burst with a loud report, a rent occurring in one of the longitudinal seams and continuing across the adjacent solid plate to within a short distance of the other end, as shown in figure 10.

The top and bottom end plates had received respectively permanent bulges of $\frac{3}{16}$-inch and $\frac{1}{4}$-inch. By referring to the sketches it will be seen that the difference is due to the fact of the latter being connected to the inner tube by a flange on the plate itself, whilst the former was connected by means of an angle iron, so that the length of the plate for bending was practically reduced.

Towards the conclusion of the experiment the scale cracked off the inside of the tube in flakes under the severe compressive stress to which it was subjected, cracking sounds being emitted, but no appreciable collapse was observed, although a slight reduction in diameter was observable whilst the pressure was on.

By the formula:—

$$\text{Collapsing pressure} = \frac{322{,}462 \times t^2}{L \times D}$$

which has been shown to give more reliable results than others for lap jointed tubes.

$$\left.\begin{array}{l}\text{Calculated}\\ \text{collapsing}\\ \text{pressure.}\end{array}\right\} = \frac{322{,}462 \times (\frac{1}{2})^2}{2{\cdot}1 \times 48} = 799 \text{ lbs. per square inch.}$$

The actual collapsing pressure is, however, limited by the resistance of the material to crushing. At the highest pressure applied the crushing strain per square inch in the material was

$$\frac{325 \times 48}{2 \times \frac{1}{2}} = 15{,}600 \text{ lbs. per square inch.}$$

Referring now to the fracture of the external shell, it has been suggested by some engineers that the strength of a boiler or similar structure, instead of being calculated upon the basis of the lines of weakness at riveted joints, &c., should be calculated with reference to the mean strength of the plate across the whole length of the boiler. The incorrectness of this system of calculation was fully shown by the results of the experiments carried out with the old boilers of the S.S. "Asturias," and "Ban Righ." The experiment on this superheater affords corroborative proof of the same. Rupture of the shell occurred at 325 lbs. per square inch, but by taking the mean section the calculated strength would appear to be about 558 lbs. per square inch, or 71 per cent. too great.

If the strength is calculated with the actual percentage between the rivets, but the injurious effects of punching and lap-jointing are neglected, and the strength of the plate, as in the above calculation, is assumed to be that ordinarily allowed by the Surveyors of Steam Vessels.

$$\left.\begin{array}{c}\text{Calculated}\\ \text{bursting}\\ \text{Pressure.}\end{array}\right\} = \frac{47{,}000 \times \cdot 64 \times 2 \times \frac{1}{2}}{78} = 385 \text{ lbs. per square inch,}$$

or 18 per cent. in excess of the actual bursting pressure.

For the effects of punching, &c., the Board's rules require the additions to the nominal factor of safety for this superheater of the values standing opposite D.I.K. & T. Deducting for these we find that the calculated bursting pressure is 315 lbs. per square inch, *differing from the actual bursting pressure by only 3 per cent.* Small as is this difference, results still more accurate were obtained in the case of the boilers of SS. "Asturias" and "Ban Righ," which were burst experimentally by hydraulic pressure several years since.

In carrying out the foregoing experiments great anxiety was felt to make them as complete as possible. With this view endeavours were made to ascertain the permanent elongation of the shell circumferentially after certain increments of pressure. The increased time during which the boilers and superheaters were subject to pressure, owing to the repeated application of it after being reduced, gave the longitudinal joints of the shells time to stretch and open so much, that the leakage was in some cases more than the pump could overpower. It is to this cause that the failure to burst the forward main boiler must be attributed.

The experience gained during these experiments, as well as during the experiment recently carried out with a large Rastrick boiler at Walsall, show that unless the pumping power at disposal is very great indeed, it is better to allow no stoppage to occur when hydraulic pressure is being applied to burst a boiler, otherwise time is afforded to the joints to strain and leak considerably. The pressure should not of course be applied rapidly, otherwise it may erroneously seem that the boiler would be able to withstand a much higher pressure without leakage than is actually the case.

I am, Sir,
Your obedient Servant,
Thomas J. Richards,
Engineer Surveyor.

Thomas W. Traill, Esq.,
Engineer Surveyor-in-Chief,
Board of Trade.

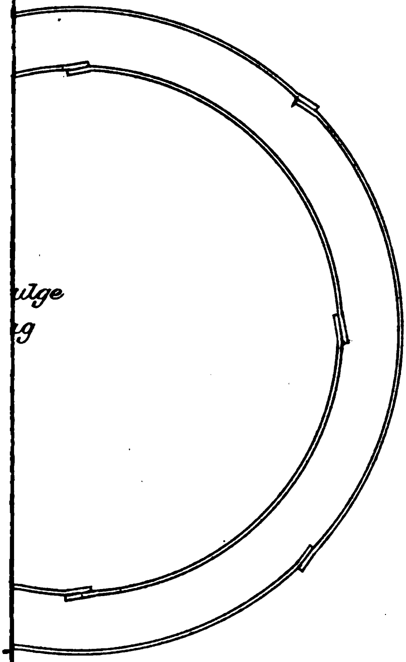
M $\frac{21087}{1880}$.

LONDON:
Printed by George E. Eyre and William Spottiswoode,
Printers to the Queen's most Excellent Majesty.
For Her Majesty's Stationery Office.

S.S. "PHAROS."

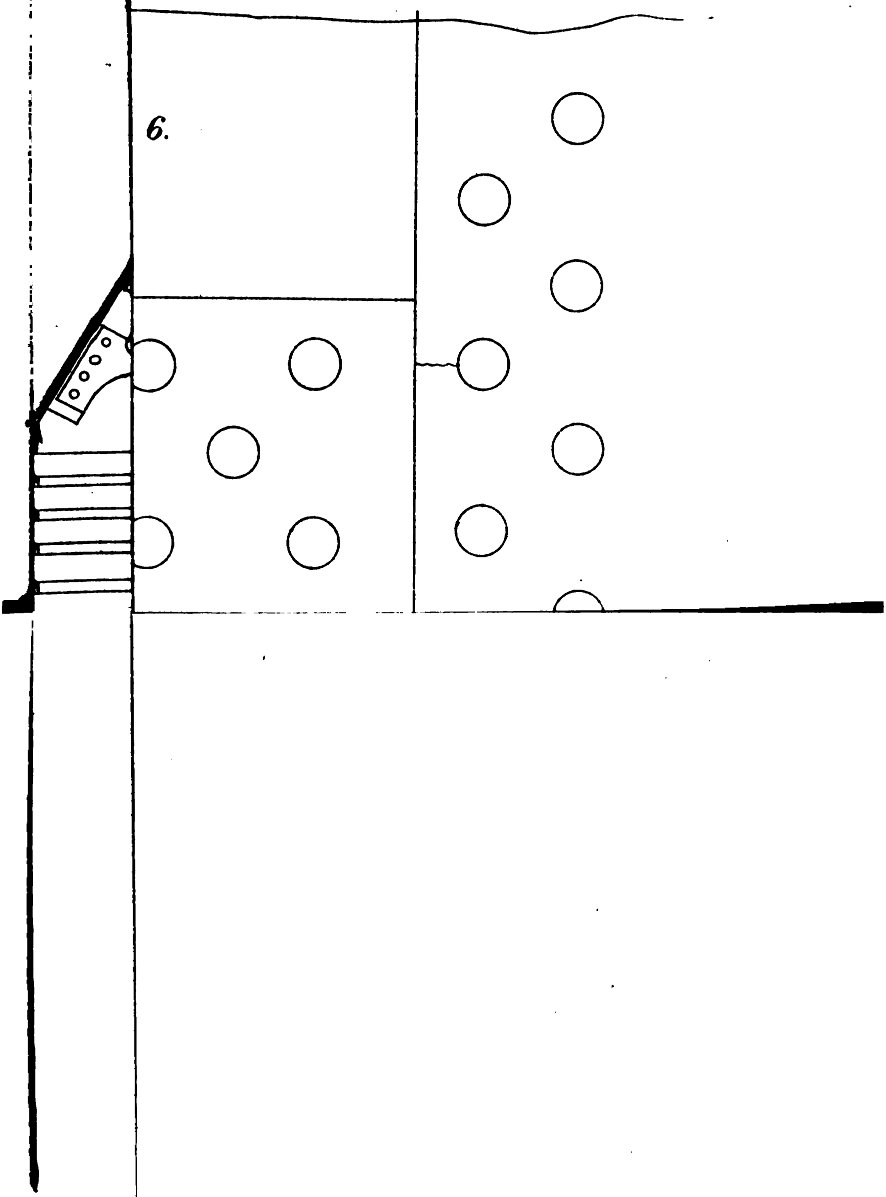
—1 Foot.

Fig 2.



DANGERFIELD. LITH. 22. BEDFORD ST COVENT GARDEN

k in shell of Forward Main Boiler at a circular Seam



TABLES

ISSUED BY THE

BOARD OF TRADE

RELATING TO

LIFE SALVAGE

THE COASTS OF THE UNITED KINGDOM
DURING THE YEAR ENDED 30TH JUNE 1880;

SHOWING

e different Life Saving Apparatus Stations, with
particulars of Services rendered by the Rocket Apparatus, and the Number of Lives saved.

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ented to both Houses of Parliament by Command of Her Majesty.

LONDON:
PRINTED BY GEORGE E. EYRE AND WILLIAM SPOTTISWOODE,
PRINTERS TO THE QUEEN'S MOST EXCELLENT MAJESTY.
FOR HER MAJESTY'S STATIONERY OFFICE.

1881.

[C.—2904.] *Price 3d.*

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Table 1.—Comparative Table of Strandings and consequent Loss of Life on the Coasts of the United Kingdom during the years 1876–7, 1877–8, 1878–9, and 1879–80, and also of the Lives saved by means of the Rocket Apparatus, Coastguard, Life Saving Brigades, and Companies.

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Table 3. List of Apparatus Stations.

Table 4.—List of Services at which Life was saved with the Rocket Life-saving Apparatus.

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REMARKS AND TABLES RELATING TO LIFE SALVAGE FOR THE YEAR ENDED 30TH JUNE 1880.

THE tables and particulars to be found in this pamphlet are made up to the 30th June 1880.

The lifeboat and the rocket apparatus form the principal means adopted for saving life on the coasts of the United Kingdom. With few exceptions the lifeboats are the property and under the management of the National Lifeboat Institution. The lifeboats at Ramsgate and Fair Isle are now the only lifeboats under the superintendence of the Board of Trade. The rocket apparatus, on the contrary, are the exclusive property of the Board of Trade.

The following is a short account of the history of the apparatus:—

The late Captain G. W. Manby, F.R.S. (born 1765, died 1854), was the inventor of the mortar apparatus, and therefore of the system of the rocket apparatus. The same idea had, however, previously occurred to Sergeant Bell, of the Royal Artillery, who, as early as 1791, devised a plan for throwing a rope on shore by means of a shell from a mortar on board the vessel in distress, or *vice versâ*, and similar experiments were made by a Frenchman, named La Fère. Manby, however, had not heard of these inventions, and his own was the first that was used. The idea occurred to him in February 1807, when present at a shipwreck, and in February of the next year he saved seven persons from a wreck by throwing a line over it, with which a boat was hauled off; and in the year after he saved several crews. The year after that (1810) the invention was brought before Parliament; again in 1814, when 45 mortar stations were established; and again in 1823, when a grant was made to him of 2,000*l.*, in addition to previous grants.

Though the Government thus took the apparatus under its protection, and it was worked by the coast guard, it was not until 1855 that the management of it was placed under a Government Department. Before this, the Shipwreck Institution, the Royal National Institution for Saving Life from Shipwreck (now called the Royal National Lifeboat Institution), and other local shipwreck societies, assisted and co-operated with the Government in establishing and supervising stations, but there was no central authority over all.

In the meantime, however, rockets had been invented and used for carrying the line. In the same year that Manby had conceived the idea of the mortar apparatus (1807), a rocket had been proposed by Mr. Trengrouse, of Helston, in Cornwall, who also proposed a kite, and a hand and lead line, as means of communication with a vessel in distress. The first and third of these proposals have borne fruit in the rocket and heaving-cane, now used at every station in the United Kingdom. His rockets were, however, too small to be effective; and it is to Mr. John Dennett, of Newport, Isle of Wight, who worked without any knowledge of Trengrouse's invention, that we owe the first rocket by which life was saved.

As early as 1826 the Royal Institution for Saving Life from Shipwreck supplied four places in the Isle of Wight with Dennett's rockets; and life was first saved by them at Bembridge in 1832. In 1853 there were about 120 stations in the United Kingdom supplied with Dennett's rockets.

In 1836 a Mr. Carte, of Hull, produced a modification of the Congreve rocket, which was supplied to about thirty-one stations, chiefly in Durham and Yorkshire. This rocket had no special advantages, and never came into general use. Both Mr. Dennett and Mr. Carte died in 1853.

In the autumn of 1852 experiments were made with an anchor shot and a grapnel shot.

When the Government took the life-saving apparatus under its own entire control in 1855, there was a large number both of rocket and mortar stations, at about half of which there were both rockets and mortars. The superiority of the rocket apparatus was acknowledged, but experiments were made by Colonel Boxer to improve both means of communication. He succeeded in improving both; the first by a new shot of a different shape, and containing fuzes, which threw a light over vessels as they passed, and the latter by a new rocket, a combination of two rockets in one case, one being a continuation of the other, so that the first compartment carried the projectile to its full elevation, and the second gave an additional impetus; the range thus obtained was found to much exceed that of two rockets attached side by side to one stick. This rocket was the same in principle as that now used.

In 1857 the Board of Trade, who had then taken over from the Customs the management of the apparatus, issued fresh instructions, which adopted almost entirely the proposals made by Commander (now Rear-Admiral) Ward, R.N., the Inspector of Lifeboats to the Lifeboat Institution, and published in *The Life Boat* for July 1853. Commander Ward was also the inventor of the cork life jacket used universally by the coast-guard, specimens of which were exhibited at the Paris Universal Exhibition of 1855. In the same exhibition there was also shown the "Travelling Life Buoy" or "Sling Life Buoy," now used with the apparatus, which was invented by Commander Kisbee, R.N.

The apparatus and the method of working it may be thus shortly described. A rocket is fired which carries a line over a ship, the crew haul on the rocket line, and this brings an endless rope (called a whip), rove through a block with a tail attached to it, which they make fast to a mast or some other portion of the wreck high above the water. Those on shore then haul off to the ship a hawser attached to the whip, which is made fast to the mast or other portion of the wreck about 18 inches above the whip. Those on shore then set the hawser up and send off to the ship the sling life buoy. When the buoy reaches the ship one of the shipwrecked persons gets into it, and it is hauled back with its occupant. This process is repeated till all, or as many as possible, are saved. On low coasts without rocks it is sometimes found better not to use the hawser, but the whip and sling life buoy alone. When the vessel is close in shore, the heaving cane is used instead of a rocket.

The use of mortars, as a means of obtaining communication with a stranded vessel, has been abandoned by the Board of Trade in favour of the rockets.

The Board of Trade issue enamelled plates with instructions to crews of vessels. These plates are supplied gratuitously to shipowners and masters for placing on their vessels in a conspicuous place. Gear is also supplied to all Royal Naval Reserve drill stations and to training ships, and every certificated officer in the mercantile marine is required to understand the working of the apparatus.

In January 1876 the Board of Trade, with the consent of the Admiralty, appointed Commander Prowse, R.N., Inspector of Life-saving Apparatus on the Coasts of the United Kingdom. They have also established a store at Poplar for the apparatus, from which all the necessary articles (except combustibles) are now issued.

The following tables show a considerable decrease in the number of lives saved by the apparatus during the year 1879–80, as compared with the previous year, as will be seen from the following statement:—

In 1879–80, the total number of lives saved by the apparatus was - - -	95
In 1878–79, Do. do. - -	162

Showing a total decrease of 67 in the number of lives saved.

The Board of Trade now grant an extra reward of 1*l.* for each life saved by the apparatus, to be divided among the coastguard and volunteers.

During the year 1879–80 the number of life saving apparatus stations (in which cliff ladder stations are included) was reduced from 294 to 289; six stations having been abolished, and a new station established at Crosshaven.

The stations abolished were:—

Burton.
Cayton.
Howth.
Lyme Cobb.
Sidmouth.
Spittal.

Wagons and carts on improved models are now supplied for the conveyance of the life saving apparatus, and an improved method of stowing the life saving gear has been introduced, which, there is reason to hope, will add to the efficiency of the service.

Special rewards for bravery and distinguished services in connection with the life saving apparatus, were given by the Board of Trade, as stated in the following list.

THOMAS GRAY.

Board of Trade,
Marine Department,
May 1881.

LIST of PERSONS to whom REWARDS were granted by the BOARD OF TRADE during the Year 1879-80, for bravery and distinguished services in connection with the ROCKET LIFE SAVING APPARATUS.

Name of Person and Name of Station.	Nature of Services rendered.	Date of Service.	Description of Reward granted.
1. Thomas Bailey, Chief Boatman; Rickham Station.	For his efficient service and praiseworthy example to those working under him at the wreck of the "Marion" when 16 lives were saved by the rocket apparatus.	7 Sept. 1879.	1*l.* in addition to the usual allowances.
2. William Tait, enrolled Volunteer; Inverallochy Station.	For brave and valuable service in assisting to man the boat "Rugby," of Inverallochy, which put off at great risk, and succeeded in rescuing the crew, six in number, of the steam tug "Superb," wrecked at Cairnbulg Briggs, when, owing to the distance of the wreck from the shore, the apparatus was unable to effect communication.	18 Oct. 1879.	1*l.* in addition to the usual allowances.
3. George Oatley, Gunner's mate and Drill Instructor; Peterhead.	For having gallantly and at the imminent risk of his own life swam off to the wreck of the Swedish schooner "Augusta" in a very heavy gale, and having been hauled on board by the crew, instructed them how to use the rocket apparatus, by means of which all on board were saved. Oatley himself was the last to leave the wreck and arrived on shore benumbed with cold, and bleeding from contact with the rocks.	16 Feb. 1880.	Albert Medal of the second class.

List of Persons to whom Rewards were granted, &c.—*cont.*

Name of Person and Name of Station.	Nature of Services rendered.	Date of Service.	Description of Reward granted.
4. Elsie Mary McClements, orphan daughter of David McClements, Commissioned Boatman; Rickham Coastguard Station.	In recognition of the gallant conduct of her late father, David McClements, who, when the Swedish schooner "Eugene" was wrecked off Rickham, went with others into the surf to attempt to rescue the sole survivor of her crew, but being overwhelmed by a heavy sea both McClements and the shipwrecked man were swept away and drowned.	16 Feb. 1880.	30*l.* to be invested for her benefit.
5. Samuel Keast, Boatman; Rickham Coastguard Station.	For courage and devotion in going into the surf at the risk of his own life to rescue the sole survivor of the wreck of the "Eugene."	16 Feb. 1880.	1*l.* in addition to the usual allowances.

TABLE 1. COMPARATIVE STATEMENT of the STRANDINGS on the COASTS of the UNITED KINGDOM during each of the Years 1876–7, 1877–8, 1878–9, and 1879–80, showing also the Number of Lives Lost by such Strandings, and also the Number of Lives saved by means of the ROCKET APPARATUS and LIFE SAVING BRIGADES and COMPANIES.

YEAR.		Vessels Stranded.			Total Stranded.	Lives Lost through Strandings.	Lives saved by Rocket Life Saving Apparatus from Vessels stranded.	Lives saved by Rocket Company by means other than the Apparatus.
		With Total Loss.	With Serious Damage.	With Minor Damage.				
1876–7	Strandings on the Coast - -	355	438	507	1,300	470	609	109
	Do. in Rivers and Harbours	5	50	134	189	2		
1877–8	Strandings on the Coast - -	262	380	518	1,160	154	119	26
	Do. in Rivers and Harbours	7	60	122	189	—		
1878–9	Strandings on the Coast -	252	336	504	1,092	146	162	35
	Do. in Rivers and Harbours	4	39	109	152	1		
1879–80	Strandings on the Coast - -	220	320	415	955	80	95	21
	Do. in Rivers and Harbours	3	40	101	144	—		
Totals for the four Years 1876–7, 1877–8, 1878–9, and 1879–80		1,108	1,663	2,410	5,181	853	985	191

TABLE 2. NUMBER of LIVES SAVED from Shipwreck on the Coasts of the United Kingdom from July 1856 to June 1880. inclusive, distinguishing the MEANS by which they were saved.

By what means saved.	1856–7.	1857–8.	1858–9.	1859–60.	1860–1.	1861–2.	1862–3.	1863–4.	1864–5.	1865–6.	1866–7.	1867–8.	1868–9.	1869–70.	1870–1.	1871–2.	1872–3.	1873–4.	1874–5.	1875–6.	1876–7.	1877–8.	1878–9.	1879–80.	TOTALS.
By life boats - -	634	120	220	367	771	322	291	472	293	480	378	377	504	532	473	403	548	310	502	461	567	489	449	322	10,285
By rocket and mortar apparatus, and assistance with ropes, &c. from shore -	383	149	154	407	415	415	252	256	347	490	527	310	333	354	203	293	715	175	355	301	817	259	269	162	8,341
By luggers, Coast Guard boats, and small craft - -	606	683	878	681	467	371	414	424	338	462	385	848	317	383	500	265	582	309	511	508	464	354	228	235	11,208
By ships and steam boats - - -	587	244	622	769	858	919	1,319	1,533	1,003	1,000	986	1,060	719	714	1,063	990	647	516	440	967	740	1,120	623	682	20,121
By ship's own boats	—	—	—	†951	1,499	1,425	1,289	1,465	1,459	2,195	2,728	1,902	2,062	2,067	2,795	1,737	1,888	1,525	1,644	1,859	1,873	1,619	1,535	1,418	36,985
By life buoys and other appliances kept on board -	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	†9	4	—	—	13
By individual exertion	21	17	16	9	14	27	9	10	22	7	13	6	—	8	2	—	6	4	6	9	1	1	6	2	216
By other means -	—	—	—	—	†362	396	531	439	232	374	765	660	561	443	459	245	388	221	379	253	324	224	192	102	7,550
TOTAL - -	2,231	1,213	1,890	3,184	4,386	3,875	4,105	4,599	3,694	5,008	5,782	5,158	4,496	4,501	5,495	3,933	4,774	3,000	3,837	4,358	4,795	4,070	3,302	2,923	94,669

* This number includes all lives saved by rocket apparatus, ropes, and similar assistance from shore, whether rendered by the life-saving parties or others.

† No records kept for former years.

LIFE SAVING APPARATUS.

TABLE 3. LIST of Places on the Coasts of the UNITED KINGDOM (Geographically arranged, and stating the Distances by the usual means of communication in bad weather), where there are Stations of the Rocket Apparatus belonging to the Board of Trade, showing those which are in the charge of the Coastguard,† and where a Rocket Brigade or Company has been formed, with the Year of Formation, and Strength on the 30th June 1880; with the Number of Lives saved by each Apparatus during the year ended on 30th June 1880; showing also the Stations to which Cliff Ladders or Lines and Belts have been supplied, and where Lifeboats are stationed; and Persons, Committees, &c., under whose management each Lifeboat is placed.†

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Orkney & Shetland:						
Lerwick	—	Belts and Lines	—	—	—	—
Fair Isle	50	Surf Lifeboat and Cliff Ladders.	Company	1878	40	—
Stromness*	70	Rocket Apparatus	Do.	1868	24	—
		Lifeboat	—	—	—	—
Longhope	15	Do.	—	—	—	—
Wick:						
Scrabster	—	Rocket Apparatus	Company	1866	23	—
		Lifeboat	—	—	—	—
Scarfskerry*	14	Rocket Apparatus	Company	1868	23	—
Huna	6	Lifeboat	—	—	—	—
Wick (Ackergill)	14	Do.	—	—	—	—
Wick	6	Rocket Apparatus	Company	1877	20	—
		Lifeboat	—	—	—	—
Inverness:						
Nairn	—	Do.	—	—	—	—
Burghead	—	Rocket Apparatus	Company	1867	25	—
Lossiemouth	10	Do.	Do.	1864	25	—
		Lifeboat	—	—	—	—
Speymouth	9	Rocket Apparatus	Company	1877	20	—
Buckie	7	Do.	Do.	1866	23	—
		Lifeboat	—	—	—	—
Cullen*	7	Rocket Apparatus	Company	1867	25	—
Portsoy	6	Do.	Do.	1866	25	—
Banff	8	Do.	Do.	1866	25	—
		Lifeboat	—	—	—	—
Fraserburgh:						
Gardenstown	9	Belts and Lines	—	—	—	—
Pennant	4	Do. do.	—	—	—	—
Rosehearty	7	Do. do.	—	—	—	—
Sandhaven	2	Do. do.	—	—	—	—
Fraserburgh	3	2 Rocket Apparatus	Company	1877	25	—
		Lifeboat	—	—	—	—
Inverallochy	5	Rocket Apparatus	Company	1869	25	—
Whitelink Bay	1	Lifeboat	—	—	—	—
Rattray Head	6	Rocket Apparatus	Company	1875	6	—
Aberdeen:						
Peterhead	10	Do.	—	—	—	5
		Lifeboat	—	—	—	—
Cruden	7	Rocket Apparatus	Company	1877	25	—
		Lifeboat	—	—	—	—

† See Note at end of Table.

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Aberdeen—*cont.*						
Collieston	9	Rocket Apparatus	Company	1875	25	—
Belhelvie	8	Do.	Do.	1877	22	—
Ythan, Mouth of	4	Lifeboat	—	—	—	—
Bridge of Don	15	Rocket Apparatus	Company	1870	25	—
Aberdeen	3	2 Lifeboats	—	—	—	—
Cove Bay	5	Rocket Apparatus	Company	1860	34	—
Muchalls	8	Do.	Do.	1870	25	—
Stonehaven	5	Do.	Do.	1866	25	—
		Lifeboat	—	—	—	—
Montrose:						
Katerline	5	Belts and Lines	—	—	—	—
Gourdon	6	Rocket Apparatus	Company	1878	24	—
		Lifeboat	—	—	—	—
Johnshaveu	3	Rocket Apparatus	Company	1866	24	—
Montrose	9	Do.	Do.	1866	25	—
		2 Lifeboats	—	—	—	—
Uzon	4	Rocket Apparatus	Company	1866	25	—
Auchmuthie	11	Belts and Lines	—	—	—	—
Arbroath	4	Rocket Apparatus	Company	1867	25	—
		Lifeboat	—	—	—	—
Westhaven	6	Rocket Apparatus	Company	1867	25	—
Buddon Ness	6	Lifeboat	—	—	—	—
Broughty Ferry	8	Do.	—	—	—	—
Burntisland:						
St. Andrews	11	Rocket Apparatus	Company	1876	25	—
		Lifeboat	—	—	—	—
Boarhills	4	Do.	—	—	—	—
Crail	6	Rocket Apparatus	Company	1875	25	—
Anstruther	4	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Elie	5	Rocket Apparatus	Company	1867	22	—
Leven	7	Belts and Lines	—	—	—	—
West Wemyss	5	Do. do.	—	—	—	—
Dysart	2	Do. do.	—	—	—	—
Burntisland	7	Do. do.	—	—	—	—
North Queensferry.	10	Do. do.	—	—	—	—
North Berwick	27	Rocket Apparatus	Company	1875	12	—
		Lifeboat	—	—	—	—
Seacliff	5	Rocket Apparatus	Company	1869	18	—
Dunbar	6	Do.	Do.	1866	25	—
		Lifeboat	—	—	—	—
Thornton Loch	6	Rocket Apparatus	Company	1877	10	—
Redheugh	7	Do.	Do.	1878	10	—
Berwick:						
Eyemouth	10	Rocket Apparatus	Company	1866	25	—
		Lifeboat	—	—	—	—
Burnmouth	3	Rocket Apparatus	Company	1866	18	—
Berwick	6	Do.	Do.	1873	24	—
Spittal	1	Lifeboat	—	—	—	—
Holy Island	12	Rocket Apparatus	Company	1872	25	—
	by boat	Lifeboat	—	—	—	—
Old Law	1	Do.	—	—	—	—
Bamburgh Castle	6	Rocket Apparatus	Company	1875	25	—
North Sunderland	4	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Beadnel*	3	Rocket Apparatus	Company	1867	25	—
Newton	3	Do.	Do.	1868	25	—
Craster	4	Do.	Do.	1866	25	—
Boulmer	4	Do.	Do.	1866	25	—
		Lifeboat	—	—	—	—

Life Saving Apparatus—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Berwick—*cont.*						
Alnmouth - -	3	Rocket Apparatus	Company	1866	25	—
		Lifeboat	—	—	—	—
Amble { North Side	4	Rocket Apparatus	Company	1873	25	—
Amble { South Side	1	Do.	Do.	1866	25	—
Hauxley - -	2	Do.	Do.	1873	25	—
		Lifeboat	—	—	—	—
Cresswell -	7	Do.	—	—	—	—
Newbiggin - -	4	Rocket Apparatus	Company	1873	25	—
		Lifeboat	—	—	—	—
Sunderland:						
North Blyth -	4	Rocket Apparatus	Company	1876	35	
		Lifeboat				—
Blyth Haven -	1	Rocket Apparatus				—
		Lifeboat	—	—	—	—
Seaton Sluice -	4	Rocket Apparatus	Company	1876	25	—
Cullercoats - -	5	Do.	Brigade	1865	100	—
		Lifeboat	—	—	—	—
Tynemouth -	2½	2 Rocket Apparatus	Brigade	1864	126	—
		2 Lifeboats	—	—	—	—
North Shields -	1	Lifeboat	—	—	—	—
South Shields -	3	2 Rocket Apparatus	Brigade	1866	100	—
		3 Lifeboats	—	—	—	—
Marsden - -	3	Rocket Apparatus	Company	1870	20	—
Whitburn - -	3	Do.	Do.	1868	25	—
		Lifeboat	—	—	—	—
North Pier, Roker	3	Rocket Apparatus	—	—	—	—
		Lifeboat				
South Pier, Sunderland.	2½	Rocket Apparatus	Brigade	1877	125	—
		2 Lifeboats				
Sunderland, South Dock Outlet.	½	Rocket Apparatus				
		Lifeboat				
Seaham Harbour -	7	Rocket Apparatus	Company	1878	25	—
		Lifeboat	—	—	—	—
Hawthorn Hythe -	3	Rocket Apparatus	—	—	—	—
Blackhalls - -	5	Do.	Company	1866	25	—
Hartlepool, East -	7	Do.	Do.	1866	23	4
		3 Lifeboats				
Middleton - -	1½	Rocket Apparatus				
Hartlepool, West -	½	Lifeboat	—	—	—	—
Stranton - -	2	Rocket Apparatus	Company	1875	24	—
		Lifeboat	—	—	—	—
Seaton Carew -	2	Rocket Apparatus	Company	1866	25	—
		Lifeboat	—	—	—	—
Middlesbrough -	18	Do.	—	—	—	—
Coatham - -	6	Rocket Apparatus	Company	1867	23	—
Redcar - -	2	2 Lifeboats	—	—	—	—
Saltburn - -	5	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Scarborough:						
Hammersea -	6	Belts and Lines	—	—	—	—
Staithes - -	4	Rocket Apparatus	Company	1867	25	—
		Lifeboat	—	—	—	—
Runswick - -	3	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Kettleness - -	4	Rocket Apparatus	Company	1872	21	—
Sandsend - -	3	Do.	Do.	1873	24	—
Upgang - -	1½	Lifeboat	—	—	—	—
Whitby (North Pier).	2	Rocket Apparatus	Company	1874	24	—
		2 Lifeboats	—	—	—	—
Whitby (South Pier).	1	Rocket Apparatus	Company	1878	25	—
Robin Hood's Bay	7	Do.	Do.	1877	18	—
		Lifeboat	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Scarborough—*cont.*						
Peak	4	Cliff Ladders	—	—	—	—
Burniston	5	Rocket Apparatus	Company	1867	20	—
Scarborough	4	Do.	Do.	1867	20	—
		Lifeboat	—	—	—	—
Filey	8	Rocket Apparatus	Company	1866	25	—
		Lifeboat	—	—	—	—
Flamborough	13	Rocket Apparatus	Company	1871	22	—
„ (North)	2	Lifeboat	—	—	—	—
„ (South)	2	Do.	—	—	—	—
Bridlington	2	Rocket Apparatus	Company	1870	9	—
		3 Lifeboats	—	—	—	—
Ulrome	8	Rocket Apparatus	Company	1865	25	—
Hornsea	5	Do.	Do.	1866	15	—
		Lifeboat	—	—	—	—
Cowden	4	Rocket Apparatus	Company	1867	14	—
Aldboro'	3	Do.	Do.	1867	15	—
Hull:						
Sandlemere	6	Do.	—	—	—	6
Withernsea	2½	Lifeboat	—	—	—	—
Holmpton	4	Rocket Apparatus	Company	1869	15	—
Easington	6	Do.	Do.	1865	16	—
Spurn Point	5	Lifeboat	—	—	—	—
Ferriby Sluice	—	Belts and Lines	—	—	—	—
Barton	4	Do. do.	—	—	—	—
Killingholme	16	Do. do.	—	—	—	—
Cleethorpes	10	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Mablethorpe:						
Horse-shoe Point	3	Belts and Lines	—	—	—	—
Donna Nook	5	Rocket Apparatus	Company	1877	22	—
		Lifeboat	—	—	—	—
Saltfleet	5	Rocket Apparatus	Company	1867	11	—
Oliver's Gap	3	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
St. Peter's	2	Belts and Lines	—	—	—	—
Theddlethorpe	5	Lifeboat	—	—	—	—
Mablethorpe	2	Belts and Lines	—	—	—	—
Sutton	4	Rocket Apparatus	Company	1875	19	—
		Lifeboat	—	—	—	—
Huttoft	4	Rocket Apparatus	Company	1878	15	—
Chapel	4	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Ingoldmells	4	Belts and Lines	—	—	—	—
Skegness	7	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Gibraltar Point	5	Belts and Lines	—	—	—	—
Wells:						
Hunstanton	23 across the Wash.	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Brancaster	8	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Burnham	4	Belts and Lines	—	—	—	—
Wells	5	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Eastern Marsh	3	Belts and Lines	—	—	—	—
Morston	4	Do. do.	—	—	—	—
Blakeney Beach	3	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Cley	2	Rocket Apparatus	Company	1875	25	—
Weybourne	5	Do.	Do.	1864	25	—
Sherringham	3	Do.	Do.	1866	25	—
		Lifeboat	—	—	—	—

Life Saving Apparatus—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Wells—*cont.*						
Cromer	4½	Rocket Apparatus	Company	1866	25	—
		Lifeboat	—	—	—	—
Great Yarmouth:						
Sidestrand*	4	Rocket Apparatus	Company	1867	10	—
Mundesley	4	Do.	Do.	1870	12	—
		Lifeboat	—	—	—	—
Bacton	3	Rocket Apparatus	Company	1866	15	5
		Lifeboat	—	—	—	—
Happisburgh	4	Rocket Apparatus	Company	1867	21	—
		Lifeboat	—	—	—	—
Palling	5	Rocket Apparatus	Company	1867	24	—
		2 Lifeboats	—	—	—	—
Thwart Lights	5	Rocket Apparatus	—	—	—	—
Winterton	2	Do.	Company	1866	19	—
		2 Lifeboats	—	—	—	—
California	3	Lifeboat	—	—	—	—
Caistor	2	Rocket Apparatus	Company	1856	14	—
		2 Lifeboats	—	—	—	—
Great Yarmouth	3	Rocket Apparatus	—	—	—	—
		2 Lifeboats	—	—	—	—
Gorleston	3	Rocket Apparatus	Company	1876	13	—
		2 Lifeboats	—	—	—	—
Corton	5	Rocket Apparatus	Company	1875	12	—
		Lifeboat	—	—	—	—
Lowestoft	3	Rocket Apparatus	—	—	—	—
		2 Lifeboats	—	—	—	—
Pakefield	2	2 Do.	—	—	—	—
Kessingland	5	Rocket Apparatus	—	—	—	—
		2 Lifeboats	—	—	—	—
Covehithe	4	Rocket Apparatus	—	—	—	—
Southwold	3	Do.	Company	1866	16	—
		2 Lifeboats	—	—	—	—
Aldboro':						
Dunwich	5	Rocket Apparatus	Company	1866	9	—
		Lifeboat	—	—	—	—
Misner Haven	2	Belts and Lines	—	—	—	—
Sizewell Gap	3	Rocket Apparatus	—	—	—	—
Thorpeness	2	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Aldboro'	3	Rocket Apparatus	Company	1872	24	—
		Lifeboat	—	—	—	—
Orfordness	5	Rocket Apparatus	Company	1875	12	—
Orford Haven	7	Do.	—	—	—	—
East Lane	2	Belts and Lines	—	—	—	—
Woodbridge Haven	2	Do. do.	—	—	—	—
Languard	5	Do. do.	—	—	—	—
Harwich:						
Pin Mill	—	Belts	—	—	—	—
Harwich	6	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Walton-on-Naze	9	Belts and Lines	—	—	—	—
Clacton-on-Sea	9	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Brightlingsea	9	Belts	—	—	—	—
West Mersea	10	Do.	—	—	—	—
Stangate	13	Do.	—	—	—	—
Bradwell	6	Do.	—	—	—	—
Burnham	16	Do.	—	—	—	—
Crouch River	4	Do.	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Southend:						
Wakering Haven -	—	Belts	—	—	—	—
Shoeburyness -	6	Do.	—	—	—	—
Southend - -	2	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Leigh - -	3	Belts	—	—	—	—
Haven Hole - -	7	Do.	—	—	—	—
Cliff Creek - -	7	Do.	—	—	—	—
Gravesend - -	5	Belts and Lines	—	—	—	—
Tilbury - -	1	Belts	—	—	—	—
Sheerness:						
Yantlett Creek -	14	Do.	—	—	—	—
Colemouth Creek -	4	Do.	—	—	—	—
Queenborough Swale.	4	Do.	—	—	—	—
Garrison Point -	2	Belts and Lines	—	—	—	—
Scrapsgate - -	2	Belts	—	—	—	—
Leysdown -	9	Belts and Lines	—	—	—	—
Shellness - -	2	Do. do.	—	—	—	—
Whitstable:						
Milton - -	—	Belts	—	—	—	—
East Swale (on H.M.S. "Cadmus").	9	Do.	—	—	—	—
Seasalter - -	3	Do.	—	—	—	—
Seasalter Cliff -	1½	Do.	—	—	—	—
Whitstable - -	1	Do.	—	—	—	—
Swale Cliff - -	3	Do.	—	—	—	—
Herne Bay - -	2	Do.	—	—	—	—
Bishopstone -	4	Do.	—	—	—	—
Reculvers - -	1	Belts and Lines	—	—	—	—
Ramsgate:						
St. Nicholas -	4	Do. do.	—	—	—	—
Epple Bay - -	2	Belts	—	—	—	—
Westgate - -	2	Do.	—	—	—	—
Margate - -	2	Do.	—	—	—	—
		3 Lifeboats	—	—	—	—
Newgate - -	2	Belts	—	—	—	—
Kingsgate - -	4	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Broadstairs -	3	Belts	—	—	—	—
		Lifeboat	—	—	—	—
Ramsgate - -	2	Do.	—	—	—	—
Pegwell Bay -	2	Belts	—	—	—	—
North Shore -	3	Do.	—	—	—	—
Deal:						
Shingle End - -	2	Belts and Lines	—	—	—	—
No. 2 Battery -	2	Do. do.	—	—	—	—
North End - -	3	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Walmer - -	1	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Kingsdown - -	2	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
St. Margaret's Bay	3	Rocket Apparatus	—	—	—	—
Folkestone:						
Casemates (Dover)	4½	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Townsend - -	2	Belts and Lines	—	—	—	—
Lydden Spout -	2	Do. do.	—	—	—	—
Pelter - - -	3	Do. do.	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
olkestone—*cont.*						
Folkestone	1	Rocket Apparatus	—	—	—	—
Sandgate	2	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Hythe	2½	Belts and Lines	—	—	—	—
Dymchurch	5	Rocket Apparatus	Company	1875	25	—
St. Mary's	2	Belts and Lines	—	—	—	—
Littlestone	1½	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Romney		Belts and Lines.	—	—	—	—
ungeness:						
No. 2 Battery	2	Rocket Apparatus	—	—	—	—
No. 1 Battery	2	Belts and Lines	—	—	—	—
		Lifeboat.	—	—	—	—
Grand Redoubt	1½	Rocket Apparatus	—	—	—	—
Dungeness	3	Do.	—	—	—	5
Galloway's	2	Belts and Lines	—	—	—	—
Lydd	2	Rocket Apparatus	—	—	—	26
Jury's Gap	3	Do.	—	—	—	—
Camber	3	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Hastings:						
Rye Harbour	2	Belts and Lines	—	—	—	—
Winchelsea	1	Lifeboat	—	—	—	—
31 Tower	2	Belts and Lines	—	—	—	—
36 Tower	3	Do. do.	—	—	—	—
Pett	3	Rocket Apparatus	—	—	—	—
Haddocks	1	Belts and Lines	—	—	—	—
Fairlight	2	Do. do.	—	—	—	—
Ecclesbourne	3	Belts	—	—	—	—
Hastings	2	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Priory	1	Belts and Lines	—	—	—	—
Bo Peep	2	Rocket Apparatus	—	—	—	—
Bexhill	3	Belts and Lines	—	—	—	—
Kewhurst	2	Do. do.	—	—	—	—
Pevensey	2	Rocket Apparatus	—	—	—	—
57 Tower	2	Belts	—	—	—	—
Langley	2	Belts and Lines	—	—	—	—
Eastbourne	3	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Brighton:						
Holywell	2	Belts and Lines	—	—	—	—
Birling Gap	4	Rocket Apparatus	—	—	—	—
Crow Link	1	Belts and Lines	—	—	—	—
Cuckmere	2	Do. do.	—	—	—	—
Blatchington	3	Rocket Apparatus	—	—	—	—
Newhaven	2	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Saltdean	5	Rocket Apparatus	—	—	—	—
Greenway	1	Belts and Lines	—	—	—	—
Blackrock	2	Do. do.	—	—	—	—
Brighton	2	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Hove	2	Belts and Lines	—	—	—	—
Fishersgate	2	Do. do.	—	—	—	—
Shoreham	3	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Lancing	2	Belts and Lines	—	—	—	—
Worthing	3	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Goring	2	Belts and Lines	—	—	—	—
Bognor:						
Kingston	3	Do. do.	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Bognor—*cont.*						
Littlehampton -	3	Belts and Lines	—	—	—	—
Elmer - -	4	Belts	—	—	—	—
Bognor - - -	3	Belts and Lines	—	—	—	—
Pagham - -	3	Belts	—	—	—	—
Wallend - - -	2	Do.	—	—	—	—
Selsey - -	1	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Thorney - -	2	Belts	—	—	—	—
Cockbush - -	4	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Chichester Harbour	3	Belts and Lines	—	—	—	—
Southsea:						
Hayling Island -	2	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Hayling Bridge -	5	Belts	—	—	—	—
Langstone Harbour	8	Do.	—	—	—	—
Southsea Castle -	2	Do.	—	—	—	—
Gosport - -	3	Do.	—	—	—	—
Clay Hall - -	1	Do.	—	—	—	—
Stokes Bay - -	2	Do.	—	—	—	—
Hill Head - -	2	Do.	—	—	—	—
Hamble River -	5	Do.	—	—	—	—
Netley - -	3	Do.	—	—	—	—
Woolston - -	3	Do.	—	—	—	—
Cowes:						
Freshwater - -	—	Rocket Apparatus	—	—	—	—
Alum Bay - -	2	Belts and Lines	—	—	—	—
Totland - -	2	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
South Yarmouth -	4	Belts and Lines	—	—	—	—
Newtown - -	7	Do. do.	—	—	—	—
Sticelett - -	3	Do. do.	—	—	—	—
East Cowes - -	2	Do. do.	—	—	—	—
Fishbourne -	5	Do. do.	—	—	—	—
Ryde - - -	3	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Spring Vale -	2	Belts and Lines	—	—	—	—
Sea View - -	1	Do. do.	—	—	—	—
Ventnor:						
Bembridge - -	2	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Ventnor - -	4	Rocket Apparatus	—	—	—	—
Reeth - -	5	Do.	—	—	—	—
St. Catherine's Point.	2	Do.	Company	1879	10	—
Atherfield - -	4	Do.	—	—	—	—
Brightstone -	4	Lifeboat	—	—	—	—
Brook - -	4	Do.	—	—	—	—
Lymington:						
Marchwood -	—	Belts and Lines	—	—	—	—
Calshot Castle -	13	Do. do.	—	—	—	—
Lepe - -	5	Do. do.	—	—	—	—
Beaulieu River -	2	Do. do.	—	—	—	—
Pitt's Deep -	4	Do. do.	—	—	—	—
Lymington -	5	Do. do.	—	—	—	—
Hurst - -	4	Do. do.	—	—	—	—
Milford - -	2	Do. do.	—	—	—	—
Barton Cliff -	6	Rocket Apparatus	Company	1869	11	—
Christchurch -	5	Belts and Lines	—	—	—	—

Life Saving Apparatus—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Swanage:						
Tuckton	5	Rocket Apparatus	—	—	—	—
Bournemouth	5	Belts and Lines	—	—	—	—
Branksea	5	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Studland Bay	3	Belts and Lines	—	—	—	—
Swanage	4	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
St. Alban's Head	9	Rocket Apparatus	—	—	—	—
Chapman's Pool	1	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Kimmeridge	6	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Weymouth:						—
Weymouth	24	Do.	—	—	—	—
Portland	5	Rocket Apparatus	—	—	—	—
Hill	2	Do.	Company	1875	6	—
Wyke	2	Do.	—	—	—	—
Langton	6	Do.	Company	1876	15	—
Lyme:						
Abbotsbury	5	Do.	—	—	—	—
Burton	5	Belts and Lines	—	—	—	—
Bridport	3	Rocket Apparatus	—	—	—	—
Chidcock	3	Belts and Lines	—	—	—	—
Charmouth	4	Do. do.	—	—	—	—
Lyme Cobb	3	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Whitlands	4	Belts and Lines	—	—	—	—
Axmouth	5	Do. do.	—	—	—	—
Beer	2	Rocket Apparatus	Company	1876	25	—
Branscombe	4	Belts and Lines	—	—	—	—
Exmouth:						
Weston	3	Do. do.	—	—	—	—
Sidmouth	3	Lifeboat	—	—	—	—
Ladram	4	Belts and Lines	—	—	—	—
Budleigh Salterton	8	Rocket Apparatus	—	—	—	—
Exmouth	4	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Dawlish	4	Belts and Lines	—	—	—	—
Teignmouth	3	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Dartmouth:						
Babbicombe	5	Belts and Lines	—	—	—	—
Torquay	3	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Paignton	4	Rocket Apparatus	—	—	—	—
Brixham	5	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Mansands	4	Belts and Lines	—	—	—	—
Kingswear	4	Do. do.	—	—	—	—
Dartmouth	½	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Blackpool	4	Belts and Lines	—	—	—	—
Tor Cross	4	Do. do.	—	—	—	—
Hallsands	3	Do. do.	—	—	—	—
Salcombe:						
Prawle	6	Rocket Apparatus	Company	1878	12	—
Rickham	3	Do.	—	—	—	16
Salcombe	2	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Hope Cove	5	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Salcombe—*cont.*						
Challaboro'	5	Rocket Apparatus	—	—	—	—
Mothercombe	5	Belts and Lines	—	—	—	—
Plymouth:						
Yealm	15	Belts	—	—	—	—
		Lifeboat	—	—	—	—
Bovisand	6	Belts and Lines	—	—	—	—
Mount Batten	3	Rocket Apparatus	—	—	—	—
Stonehouse	7	Belts	—	—	—	—
		Lifeboat	—	—	—	—
Cawsand	4	Belts	—	—	—	—
Polhawn	2	Do.	—	—	—	—
Portwrinkle	7	Rocket Apparatus	Company	1866	12	—
Downderry	3	Belts	—	—	—	—
Looe	5	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Fowey:						
Polperro	4	Belts and Lines	—	—	—	—
Fowey	6	Do. do.	—	—	—	—
Polkerris	2½	Lifeboat	—	—	—	—
Par	2	Belts	—	—	—	—
Charlestown	4	Rocket Apparatus	—	—	—	—
Mevagissey	7	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Gorran Haven	3	Belts and Lines	—	—	—	—
Port Looe	7	Belts	—	—	—	—
		Lifeboat	—	—	—	—
Gerran's Bay	7	Rocket Apparatus	Company	1877	13	—
Falmouth:						
St. Mawes	3	Belts and Lines	—	—	—	—
Falmouth	4	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Porthillick	7	Belts and Lines	—	—	—	—
Porthoustock	5	Lifeboat	—	—	—	—
Coverack	4	Rocket Apparatus	Company	1877	14	—
Cadgwith	7	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Lizard	3	Rocket Apparatus	Company	1877	11	—
		Lifeboat	—	—	—	—
Mullion	5	Rocket Apparatus	Company	1877	12	3
		Lifeboat	—	—	—	—
Gunwallos	3½	Belts and Lines	—	—	—	—
Porthleven	3½	Rocket Apparatus	Company	1877	12	—
		Lifeboat	—	—	—	—
Penzance:						
Prussia Cove	7	Rocket Apparatus	—	—	—	—
Marazion	4	Do.	Company	1869	12	—
Penzance	3	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Mousehole	3	Rocket Apparatus	—	—	—	—
Penberth	7	Belts and Lines	—	—	—	—
Sennen Cove	5	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Pendeen Cove	7	Rocket Apparatus	—	—	—	—
St. Ives	13	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Hayle:						
Hayle	5	Do.	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Padstow:						
Gwithian	5	Belts and Lines	—	—	—	—
Portreath	8	Rocket Apparatus	Company	1871	18	—
Port Towan	4	Belts and Lines	—	—	—	—
St. Agnes	4	Rocket Apparatus	Company	1870	18	4
Perran Porth	5	Belts and Lines	—	—	—	—
Newquay	8	Rocket Apparatus	Company	1866	18	—
		Lifeboat	—	—	—	—
Mawgan Porth	6	Rocket Apparatus	Company	1866	18	—
Trevose Head	8	Do.	Do.	1866	15	—
Cregmeer	4	Do.	Do.	1866	14	—
Stepper Point	3	Do.	Do.	1868	13	—
Harbour Cove	¾	Lifeboat	—	—	—	—
St. George's Cove	1	Belts and Lines	—	—	—	—
Trebetherick	2 by boat.	Rocket Apparatus	Company	1866	15	—
Polzeath	1	Belts and Lines	—	—	—	—
Port Isaac	6	Rocket Apparatus	Company	1865	18	—
		Lifeboat	—	—	—	—
Boscastle	12	Rocket Apparatus	Company	1866	18	—
Budehaven	17	Do.	Do.	1866	18	—
		Lifeboat	—	—	—	—
Ilfracombe:						
Clovelly Harbour	23	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Clovelly	2	Rocket Apparatus	—	—	—	—
Westward Ho!	13	Do.	Company	1870	4	—
Appledore	2	2 Lifeboats	—	—	—	—
Braunton	12	Lifeboat	—	—	—	—
Croyde	4	Rocket Apparatus	Company	1870	12	—
		Lifeboat	—	—	—	—
Morthoe	6	Rocket Apparatus	Company	1865	13	—
		Lifeboat	—	—	—	—
Ilfracombe	6	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Combe Martin	6	Belts	—	—	—	—
Lynmouth	13	Rocket Apparatus	Company	1866	10	—
		Lifeboat	—	—	—	—
Porlock	13	Belts and Lines	—	—	—	—
Minehead	9	Do. do.	—	—	—	—
Watchet	9	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Burnham	17	Do.	—	—	—	—
Weston-super-Mare	—	Belts and Lines	—	—	—	—
Swansea:						
Penarth	—	Rocket Apparatus	Company	1874	10	—
		Lifeboat	—	—	—	—
Barry	8	Rocket Apparatus	Company	1866	14	—
Porthcawl	26	Do.	Do.	1872	25	—
		Lifeboat	—	—	—	—
Mumbles	25	Rocket Apparatus	Company	1875	25	—
		Lifeboat	—	—	—	—
Oxwich	10	Rocket Apparatus	Company	1857	25	—
Rhossily	8	Do.	Do.	1877	25	—
Burry Port (Pembrey).	20	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Ferryside	10	Do.	—	—	—	—
Milford:						
Tenby	—	Rocket Apparatus	Company	1874	22	—
		Lifeboat	—	—	—	—
Castletank	16	Rocket Apparatus	—	—	—	—
Linney Head	5½	Cliff Ladders	—	—	—	—

Life Saving Apparatus—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Milford—*cont.*						
Angle	5	Rocket Apparatus	Company	1874	28	—
		Lifeboat	—	—	—	—
St. Ann's Head	30	Cliff Ladders	—	—	—	—
		Belts and Lines	—	—	—	—
Runwayskiln*	5	Rocket Apparatus	Company	1874	20	—
Littlehaven	8	Do.	Do.	1874	15	—
Solva	7	Lifeboat	—	—	—	—
St. David's	4	Rocket Apparatus	Company	1877	20	—
St. Justinian	2½	Lifeboat	—	—	—	—
Goodwick	16	Rocket Apparatus	Company	1877	18	—
		2 Lifeboats	—	—	—	—
Newport	9	Rocket Apparatus	Company	1874	12	—
Penrhyn	8	Do.	Do.	1874	16	—
		Lifeboat	—	—	—	—
Gobert	12	Rocket Apparatus	Company	1873	11	—
Newquay	28	Do.	Do.	1879	20	—
		Lifeboat	—	—	—	—
Aberystwith:						
Aberystwith	12	Do.	—	—	—	—
Aberdovey	12	Do.	—	—	—	—
Barmouth	16	Do.	—	—	—	—
Carnarvon:						
Criccieth	16	Do.	—	—	—	—
	by water					—
Abersoch	15	Do.	—	—	—	—
Porthdynllaen*	10	Rocket Apparatus	Company	1864	25	—
		Lifeboat	—	—	—	—
Llanddwyn	16	Do.	—	—	—	—
Carnarvon	7	Belts and Lines	—	—	—	—
Liverpool:						
Rhosniger	11	Rocket Apparatus	Company	1875	24	—
		Lifeboat	—	—	—	—
Rhoscollyn	6	Do.	—	—	—	—
Holyhead	11	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Cemlyn	13	Do.	—	—	—	—
Cemaes	2½	Rocket Apparatus	Company	1873	25	—
		Lifeboat	—	—	—	—
Bull Bay	4	Do.	—	—	—	—
Amlwch	2	Rocket Apparatus	Company	1872	25	—
Moelfra	9	Lifeboat	—	—	—	—
Penmon	7	Do.	—	—	—	—
Bangor	11	Belts	—	—	—	—
Llandudno	16	Lifeboat	—	—	—	—
Llandullas	7	Do.	—	—	—	—
Rhyl	7	Belts and Lines	—	—	—	—
		2 Lifeboats	—	—	—	—
Point of Ayre	8	2 do.	—	—	—	—
Helbre Island	32	2 do.	—	—	—	—
Hoylake	2	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
New Brighton	8	Belts and Lines	—	—	—	—
		2 Lifeboats	—	—	—	—
Liverpool (Landing Stage).	4	2 do.	—	—	—	—
Waterloo	5	Belts and Lines	—	—	—	—
Formby	5	Lifeboat	—	—	—	—
Southport	4	Do.	—	—	—	—
Lytham	25	Do.	—	—	—	—
Blackpool	7	Do.	—	—	—	—
Fleetwood	12	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Piel	57	Do.	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Liverpool—*cont.*						
Seascale	36	Lifeboat	—	—	—	—
Whitehaven*	13	Rocket Apparatus	Brigade	1868	25	5
		Lifeboat	—	—	—	—
Workington*	6	Rocket Apparatus	Brigade	1878	38	—
Maryport	6	Belts and Lines	—	—	—	—
		Lifeboat	—	—	—	—
Silloth	12	Do.	—	—	—	—
Dumfries:						
Kirkcudbright	—	Do.	—	—	—	—
Greenock:						
Isle of Whithorn	—	Do.	—	—	—	—
Drumore	—	Rocket Apparatus	Company	1869	23	—
Port Logan	5	Do.	Do.	1869	18	—
		Lifeboat	—	—	—	—
Port Patrick	13	Rocket Apparatus	Company	1873	20	—
		Lifeboat	—	—	—	—
Stranraer	7	Belts and Lines	—	—	—	—
Cairn Ryan	6	Do. do.	—	—	—	—
Ballantrae	9	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Girvan	14	Do.	—	—	—	—
Ayr	11	Do.	—	—	—	—
Troon	5	Do.	—	—	—	—
Irvine	6	Do.	—	—	—	—
Ardrossan	9	Rocket Apparatus	Company	1869	20	—
		Lifeboat	—	—	—	—
Largs	12	Belts and Lines	—	—	—	—
Gourock	13	Do. do.	—	—	—	—
Isle of Arran:						
Lamlash	—	Do. do.	—	—	—	—
Kildonan	10	Rocket Apparatus	Company	1877	20	4
		Lifeboat	—	—	—	—
Campbeltown:						
Campbeltown	—	Do.	—	—	—	—
Southend	10	Do.	—	—	—	—

IRELAND.

Moville:						
Malin Head	24	Belts and Lines	—	—	—	—
Culdaff	12	Belts	—	—	—	—
Port Kinnagoe	10	Belts and Lines	—	—	—	—
Greencastle	8	Rocket Apparatus	Company	1878	13	—
		Lifeboat	—	—	—	—
Moville Detachment	3	Belts and Lines	—	—	—	—
Moville Station	1	Do. do.	—	—	—	—
Ballycastle (Antrim):						
Bannmouth	—	Belts and Lines	—	—	—	—
Port Stewart	3	Do. do.	—	—	—	—
Port Rush	4	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Ballintrae	5	Belts and Lines	—	—	—	—
Ballintoy	9	Do. do.	—	—	—	—
Ballycastle	6	Do. do.	—	—	—	—
Torr Head	8	Do. do.	—	—	—	—
Cushenden	5	Do. do.	—	—	—	—
Cushendall	4	Do. do.	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Carrickfergus:						
Carnlough	10	Belts and Lines	—	—	—	—
Glenarm	3	Do. do.	—	—	—	—
Ballygally	7	Do. do.	—	—	—	—
Larne	6	Do. do.	—	—	—	—
Ballylig	5	Do. do.	—	—	—	—
Brown's Bay	9	Do. do.	—	—	—	—
Port Muck	4	Do. do.	—	—	—	—
Hillsport	6	Do. do.	—	—	—	—
Whitehead	4	Do. do.	—	—	—	—
Carrickfergus	5	Do. do.	—	—	—	—
Whitehouse	6	Do. do.	—	—	—	—
Donaghadee:						
Donaghadee	3½	Do. do.	—	—	—	—
Orlock Hill	2	Do. do.	—	—	—	—
Groomsport	3	Rocket Apparatus Lifeboat	— —	— —	— —	— —
Bangor	3	Belts and Lines	—	—	—	—
Clandeboye	4	Do. do.	—	—	—	—
Cultra	4	Do. do.	—	—	—	—
Clogher	7½	Do. do.	—	—	—	—
Burr Point	3	Do. do.	—	—	—	—
Roddens	3	Do. do.	—	—	—	—
Ballywalter	2	Lifeboat	—	—	—	—
Millisle	3	Belts and Lines	—	—	—	—
Strangford:						
Tara	—	Do. do.	—	—	—	—
Portaferry	4	Do. do.	—	—	—	—
Strangford	1	Do. do.	—	—	—	—
Killard	4	Do. do.	—	—	—	—
Gunn's Island	3	Do. do.	—	—	—	—
Newcastle:						
Ardglass	5	Do. do.	—	—	—	—
Killough	4	Do. do.	—	—	—	—
St. John's Point	3	Do. do.	—	—	—	—
Tyrella	6	Belts Lifeboat	— —	— —	— —	— —
Dundrum	5	Belts and Lines	—	—	—	—
Newcastle	5	Do. do. Lifeboat	— —	— —	— —	— —
William's Harbour	4	Belts and Lines	—	—	—	—
Annalong	5	Rocket Apparatus	Company	1866	18	—
Leestone	5	Belts and Lines	—	—	—	—
Carlingford:						
Cranfield	7	Do. do.	—	—	—	—
Killoween	5	Do. do.	—	—	—	—
O'Meath	7	Do. do.	—	—	—	—
Carlingford	5	Belts	—	—	—	—
Greenore	4	Belts and Lines	—	—	—	—
Giles Quay	9	Do. do. Lifeboat	— —	— —	— —	— —
Soldier's Point	6	Belts and Lines	—	—	—	—
Annagassan	10	Do. do.	—	—	—	—
Dunany Point	4	Do. Do.	—	—	—	—
Clogher Head	8	Rocket Apparatus	Company	1879	25	—
Drogheda	7	Do. do. 2 Lifeboats	— —	— —	— —	— —
Malahide:						
Laytown	6*	Rocket Apparatus	—	—	—	—
Balbriggan	5	Do. Lifeboat	— —	— —	— —	— —

Life Saving Apparatus—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Malahide—*cont.*						
Skerries	4	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Loughshinney	3	Belts and Lines	—	—	—	—
Rush	2	Belts	—	—	—	—
Rogerstown	1	Lifeboat	—	—	—	—
Portrane	2	Rocket Apparatus	—	—	—	—
Lambay Island	3 by sea	Belts and Lines	—	—	—	—
Malahide	5 from Portrane.	Do. do.	—	—	—	—
Baldoyle	4½	Do. do.	—	—	—	—
Dublin:						
Howth	3	Lifeboat	—	—	—	—
Needles	2½	Belts and Lines	—	—	—	—
Sutton	1½	Do. do.	—	—	—	—
Clontarf	4½	Do. do.	—	—	—	—
Ringsend	5	Do. do.	—	—	—	—
		Lifeboat	—	—	—	—
Kingstown	7	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Dalkey	3	Belts and Lines	—	—	—	—
Bray	6	Rocket Apparatus	Company	1866	24	—
Greystones	5	Do.	Do.	1861	25	—
		Lifeboat	—	—	—	—
Arklow:						
Five Mile Point	6	Rocket Apparatus	—	—	—	—
Wicklow Head	6	Do.	Company	1865	11	—
		Lifeboat	—	—	—	—
Jack's Hole	6	Rocket Apparatus	Company	1878	12	—
Mizen Head	3	Belts and Lines	—	—	—	—
Arklow	7	Rocket Apparatus	Company	1865	10	—
		Lifeboat	—	—	—	—
Kilmichael	7	Rocket Apparatus	—	—	—	—
Ballymoney	7	Belts and Lines	—	—	—	—
Courtown	4	Rocket Apparatus	Company	1865	13	—
		Lifeboat	—	—	—	—
Cahore	8	Rocket Apparatus	Company	1866	20	—
		Lifeboat	—	—	—	—
Wexford:						
Morris Castle	7	Rocket Apparatus	Company	1872	7	—
Curracloe	12	Do.	Do.	1872	15	—
Wexford (Rosslare Fort).	5	Do.	—	—	—	—
		2 Lifeboats	—	—	—	—
Wexford* (Rosslare Boarding Station).	7	Rocket Apparatus	—	—	—	—
Carnsore	8	Do.	—	—	—	—
		Lifeboat	—	—	—	—
Kilmore	14	Rocket Apparatus	—	—	—	12
Bar of Lough	6	2 Do.	—	—	—	—
Waterford:						
Fethard	4	1 Do.	Company	1857	20	—
Duncannon	8	Lifeboat	—	—	—	—
Arthurstown	3	Belts and Lines	—	—	—	—
Dunmore	9	Rocket Apparatus	—	—	—	—
Ballymacaw	4	Do.	Company	1874	22	—
Tramore	9	Do.	Do.	1868	20	—
		Lifeboat	—	—	—	—
Bonmahon	10	Rocket Apparatus	Company	1869	4	—
Youghal:						
Ballynacourty	12	Belts	—	—	—	—
		Lifeboat	—	—	—	—
Helvick Head	13	Belts and Lines	—	—	—	—

Life Saving Apparatus—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Youghal—*cont.*						
Ardmore	14	Rocket Apparatus	Company	1874	22	—
		Lifeboat	—	—	—	—
Youghal	9	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Knockadoon	12	Belts and Lines	—	—	—	—
Queenstown:						
Ballycotton	7	Rocket Apparatus	Company	1879	13	—
		Lifeboat	—	—	—	—
Ballycrooneen	7	Rocket Apparatus	—	—	—	—
Poor Head	4	Do.	—	—	—	—
Roche's Point	4	Belts and Lines	—	—	—	—
East Ferry	10	Belts	—	—	—	—
Crosshaven	17	Rocket Apparatus	—	—	—	—
Myrtleville	4	Belts and Lines	—	—	—	—
Queenstown	4	Lifeboat	—	—	—	—
Kinsale:						
Robert's Cove	8	Rocket Apparatus	Company	1866	11	—
Oyster Haven	10	Do.	Do.	1866	16	—
Old Head	18	Do.	Do.	1866	18	—
Courtmacsherry	18	Do.	Do.	1868	19	—
		Lifeboat	—	—	—	—
Barry's Cove	6	Rocket Apparatus	Company	1865	20	—
Dirk Cove	19	Do.	Do.	1866	21	—
Skibbereen:						
Castlefreke*	3	Do.	Company	1867	25	—
Ross	5	Belts	—	—	—	—
Mill Cove	2	Rocket Apparatus	Company	1867	25	—
Union Hall	5	Belts and Lines	—	—	—	—
Castletownsend	3	Rocket Apparatus	Company	1877	12	—
Barlogue	7	Belts	—	—	—	—
Baltimore	6	Rocket Apparatus	Company	1866	18	—
Schull	24	Belts and Lines	—	—	—	—
Crookhaven	12	Rocket Apparatus	Company	1866	12	—
Castletown:						
Lawrence's Cove	—	Belts and Lines	—	—	—	—
Castletown	6	Do. do.	—	—	—	—
Ballycrovane	8	Do. do.	—	—	—	—
Ballydonegan	16	Do. do.	—	—	—	—
Killarney:						
Lackeen Point	—	Do. do.	—	—	—	—
Waterville	32	Do. do.	—	—	—	—
Ballinskelligs	11	Do. do.	—	—	—	—
Port Magee	11	Do. do.	—	—	—	—
Knightstown (Valentia).	5	Rocket Apparatus	—	—	—	—
		Lifeboat	—	—	—	—
Cahirciveen	4	Belts and Lines	—	—	—	—
Kells	10	Do. do.	—	—	—	—
Cromane Point	18	Do. do.	—	—	—	—
Minnard	14	Do. do.	—	—	—	—
Dingle	10	Rocket Apparatus	—	—	—	—
Ventry	7	Belts and Lines	—	—	—	—
Ballydavid	10	Do. do.	—	—	—	—
Ballyheigue:						
Barrow	52	Lifeboat	—	—	—	—
		Belts and Lines	—	—	—	—
Ballyheigue	15	Rocket Apparatus	Company	1876	12	—
Cashen	15	Belts and Lines	—	—	—	—
Tarbert	15	Do. do.	—	—	—	—

LIFE SAVING APPARATUS—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
Seafield:						
Cappa - -	—	Belts and Lines	—	—	—	—
Kilcredane - -	9	Do. do.	—	—	—	—
Kilkee - -	8	Do. do.	—	—	—	—
Seafield - -	16	Do. do.	—	—	—	—
Liscanor - -	14	Do. do.	—	—	—	—
Galway:						
North Arran -	—	Do. do.	—	—	—	—
South Arran - -	6	Do. do.	—	—	—	—
Ballyvaughan -	20	Do. do.	—	—	—	—
Barna - -	30	Do. do.	—	—	—	—
Spiddal - - -	8	Do. do.	—	—	—	—
Costello Bay -	10	Do. do.	—	—	—	—
Clifden:						
Roundstone - -	—	Do. do.	—	—	—	—
Bunowen - -	14	Do. do.	—	—	—	—
Bayleek - -	12	Do. do.	—	—	—	—
Cleggan - -	10	Do. do.	—	—	—	—
Ballinakill - -	6	Do. do.	—	—	—	—
Tully - -	6	Do. do.	—	—	—	—
Rosmoney - -	30	Do. do.	—	—	—	—
Keel:						
Achill Beg - -	—	Do. do.	—	—	—	—
Keel - - -	16	Do. do.	—	—	—	—
Doogort - -	5	Do. do.	—	—	—	—
Bullsmouth - -	10	Belts	—	—	—	—
Belmullet:						
Blacksod - -	—	Belts and Lines	—	—	—	—
Elly Bay - -	7	Do. do.	—	—	—	—
Ballyglass - -	14	Do. do.	—	—	—	—
Claggan Island -	11	Do. do.	—	—	—	—
Doohooma -	9	Do. do.	—	—	—	—
Ballycastle (Killala):						
Ballycastle - -	—	Do. do.	—	—	—	—
Kilcummin -	9	Do. do.	—	—	—	—
Ross - - -	9	Do. do.	—	—	—	—
Pullendiva:						
Inniscrone - -	—	Do. do.	—	—	—	—
Pullocheney - -	6	Do. do.	—	—	—	—
Pullendiva - -	10	Do. do.	—	—	—	—
Derkmore - -	10	Do. do.	—	—	—	—
Sligo:						
Rosses Point -	—	Do. do.	—	—	—	—
Rackly - - -	15	Do. do.	—	—	—	—
Mullaghmore -	15	Do. do.	—	—	—	—
Ballyshannon -	14	Do. do.	—	—	—	—
Killybegs:						
Dooran - -	14	Do. do.	—	—	—	—
Tribane - -	14	Do. do.	—	—	—	—
Killybegs - -	6	Rocket Apparatus	Company	1877	12	—
Teelin - - -	16	Belts and Lines	—	—	—	—
Malinmore - -	10	Do. do.	—	—	—	—
Lochrus - -	15	Do. do.	—	—	—	—
Portnoo - -	13	Rocket Apparatus	Company	1861	22	—
Dunfanaghy:						
Inishbofin - -	—	Belts and Lines	—	—	—	—
Sheephaven -	12	Do. do.	—	—	—	—
Mulroy - -	14	Do. do.	—	—	—	—
Knockallow -	13	Do. do.	—	—	—	—
Buncrana - -	4	Belts	—	—	—	—
Rathmullen - -	3	Do.	—	—	—	—

Life Saving Apparatus—*continued.*

Names of Divisions and Stations.	Distance in Miles from preceding Station.	Means of Saving Life.				
		Description.	Brigade or Company.			No. of Lives saved by Rocket Apparatus.
			Description.	Year of Formation.	Strength on 30th June 1880.	
ISLANDS.						
Scilly:						
St. Mary's	—	Rocket Apparatus	Company	1873	18	—
		Lifeboat	—	—	—	—
Tresco	3	Rocket Apparatus	Company	1875	14	—
Liverpool:						
Isle of Man:—						
Peel*	—	Do.	Company	1867	25	—
Ramsey*	17	Do.	Do.	1866	31	—
		Lifeboat	—	—	—	—
Douglas*	17	Rocket Apparatus	Company	1867	28	—
		2 Lifeboats	—	—	—	—
Castletown*	10	Rocket Apparatus	Company	1869	32	—
		Lifeboat	—	—	—	—
Jersey:						
St. Helier's	—	Do.	—	—	—	—
St. Peter's*	—	Rocket Apparatus	—	—	—	—
Guernsey:						
Lancresse Bay	—	Belts	—	—	—	—
		Lifeboat	—	—	—	—
Alderney:						
Braye	—	Do.	—	—	—	—
Sheerness:						
Heligoland:—						
Heligoland	—	Rocket Apparatus	—	—	—	—
Sandy Island	—	Do.	—	—	—	—

†N.B.—With the exception of the stations marked thus *, at which no coastguard is stationed, the rocket apparatus is in all cases under the charge of the coastguard; and all the lifeboats mentioned in this table are the property and under the management of the National Lifeboat Institution, with the following exceptions:—

Fair Isle	under the	management of the	Board of Trade.
Wick	„	„	Harbour Trust Committee.
Aberdeen (2 boats)	„	„	Harbour Commissioners.
Boarhills	„	„	Private Persons.
N. Shields	„	„	Harbour Commissioners.
S. Shields (3 boats)	„	„	„ „
Redcar (1 boat)	„	„	Local Committee.
Robin Hood's Bay	„	„	Local Shipowners.
Bridlington (2 boats)	„	„	Private Persons.
Spurn Point	„	„	Hull Trinity House.
Corton	„	„	Private Persons.
California	„	„	„ „
Gorleston (1 boat)	„	„	Local Boatmen.
Margate (1 boat)	„	„	Borough of Margate.
„ „	„	„	Local Boatmen.
Ramsgate	„	„	Board of Trade.
Totland	„	„	Private Persons.
Ryde	„	„	Town Corporation.
Croyde	„	„	Private Persons.
Point of Ayre (2 boats)	„	„	Mersey Dock and Harbour Board.
Helbre Island (2 boats)	„	„	„ „
Hoylake	„	„	„ „
Liverpool (2 boats)	„	„	„ „
Formby	„	„	„ „
St. Helier's	„	„	Local Authorities.

SUMMARY.

—	No. of Places supplied with																																						
	Life Saving Apparatus.																							Belts and Lines.															
	1857.	1858.	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	Jan. to June 1873.	1873–4.	1874–5.	1875–6.	1876–7.	1877–8.	1878–9.	1879–80.	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	Jan. to June 1873.	1873–4.	1874–5.	1875–6.	1876–7.	1877–8.	1878–9.	1879–80.
England and Wales.	140	157	156	167	166	167	167	166	169	177	182	185	187	188	187	191	194	194	184	186	185	189	191	186	226	327	339	323	336	318	318	304	311	312	309	322	328	317	344	*198	203
Scotland -	24	22	23	25	28	29	29	32	33	36	40	41	42	43	41	38	38	40	38	39	40	42	44	44	37	43	47	38	40	40	33	30	31	39	38	36	41	36	38	20	19
Ireland -	34	37	37	41	41	42	43	44	46	48	48	49	49	49	49	49	50	49	48	49	50	51	52	52	137	181	192	185	201	199	196	169	166	185	184	190	192	184	198	147	143
Isle of Man -	—	—	—	—	—	—	—	1	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	3	2	2	2	—	—	—	—	—	—	—	1	—	—	—
Channel Islands.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Heligoland -	—	—	—	—	—	—	—	—	—	—	—	2	2	2	2	2	2	2	2	2	2	2	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
Total -	198	216	216	233	235	238	239	243	249	265	274	281	284	286	283	284	288	289	276	280	282	289	294	289	402	553	581	548	579	559	547	503	508	537	531	548	561	539	581	365	366

* The diminution in the numbers in this column as compared with previous years is owing to the omission of all stations where there is a Life Saving Apparatus as well as Belts and Lines.

SUMMARY—*continued*.

	No. of Lifeboats.																										No. of Lives saved by Rocket Apparatus.										
	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	Jan. to June 1873.	1873–4.	1874–5.	1875–6.	1876–7.	1877–8.	1878–9.	1879–80.	1870.	1871.	1872.	Jan. to June 1873.	1873–4.	1874–5.	1875–6.	1876–7.	1877–8.	1878–9.	1879–80.
England and Wales - -	127	124	141	149	158	173	179	179	178	186	192	207	222	228	254	257	261	261	263	197	201	320	207	214	212	212	85	135	174	82	42	174	146	484	101	136	74
Scotland - -																				33	34	34	36	41	42	45	—	10	14	—	18	18	40	63	18	7	9
Ireland - -																				30	31	32	32	32	33	33	19	39	38	6	68	6	31	39	—	19	12
Isle of Man -																				4	4	4	4	4	4	4	2	—	4	—	—	—	—	23	—	—	—
Channel Islands																				3	3	3	3	3	3	3	—	—	—	—	—	—	—	—	—	—	—
Heligoland - -	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—
Total - -	127	124	141	149	158	173	179	179	178	186	192	207	222	228	254	257	261	261	263	267	273	276	282	294	294	297	106	184	230	88	128	198	220	609	119	162	95

TABLE 4. LIST and PARTICULARS of the Occasions during the Year ended 30th June 1880 on which the LIFE-SAVING APPARATUS was instrumental in Saving Life.

Date of Service.	Name of Rocket Apparatus Station.	No. of Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives saved.	No. of Lives lost.	Particulars of the Service.
1879. 1 Aug. -	St. Agnes -	4	21	"Hannah Louisa," east side of Perran Beach.	4	—	Wind at force 4. Weather clear.* Time, 4 p.m. This was a very good service, accomplished in spite of unusual difficulties. The horses of the messengers had to be impressed to draw the apparatus to the scene of wreck, and the vessel was so far from shore that the tackle fall had to be bent on to the hawser to make it long enough. Notwithstanding these obstacles the first man was landed 10 minutes after firing the first rocket, and the whole of the crew, were safely brought ashore by the apparatus.
7 Sept. -	Rickham - -	13	18	"Meirion," Rickham Sands.	16	—	Wind at force 5. Weather squally. Time, 3 a.m. Communication was effected, but the landing of the crew was attended with difficulty, owing to the heavy rolling of the ship and the surf on the beach. The whole of the shipwrecked men, were however safely hauled ashore by the rocket party. A gratuity of 1*l.* in addition to the usual allowances was awarded to Thos. Bailey, chief boatman, to mark the approval of the Board of Trade of the efficient manner in which he worked the apparatus in the absence of his superior officer.

* The time mentioned in this column, if not otherwise stated, is the time of arrival of the rocket party at the scene of the wreck.

TABLE 4—*continued.*

Date of Service.	Name of Rocket Apparatus Station.	No. of Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives saved.	No. of Lives lost.	Particulars of the Service.
1879. 23 Sept. -	Kildonan -	2	18	"Jennie Blair," Drumly.	4	—	Wind at force 9. Weather rainy and very dark. Time, 2.55 a.m. Notwithstanding the tempestuous state of the weather and the heavy sea running, communication was quickly effected, and the crew safely landed in 45 minutes.
19 Oct. -	Kilmore - -	6	29	"Bayard," Ta Cumshin Bar.	12	—	Wind at force 7. Weather thick with heavy showers. Time, 4.40 a.m. When brought to the scene of wreck the apparatus had to be taken 600 yards through sand knee deep. The ship canted broadside to the sea, rolling and labouring heavily, and drifted along the shore, so that it was only after two hours hard work the shipwrecked men were rescued by the rocket party.
19 " -	Lydd - -	15	1	"Alton Tower," off Lydd Station.	26	—	Wind at force 8. Weather rainy. Time, 2.30 a.m. Communication was effected, and the whole of the crew of the shipwrecked vessel safely landed by the apparatus.

20 Nov. -	Sandlemere -	5	14	"Bertha," 1 mile S. of Withernsea Pier.	6	—	Wind at force 8. Weather squally with snow. Time, 10.30 p.m. Communication was effected with great difficulty, and not until four rockets had been fired, but eventually the whole of the shipwrecked crew were safely landed by the apparatus.
29 Dec. -	Mullion - -	6	12	"Elizabeth Hendrika," Poljew Beach.	3	—	Wind at force 8 to 9. Weather thick with rain squalls. Time, 1.40 a.m. Communication was effected and the shipwrecked crew were landed in the breeches buoy in less than an hour from the receipt of the intelligence of the wreck at the station.
1880. 19 Jan. -	No. 2 Battery, (Dungeness.)	11	8	"Eltje," off the station.	5	—	Wind at force 6. Weather thick with snow. Time, 3 a.m. Communication effected by the first rocket, and the crew safely landed by means of the apparatus.
20 "	Bacton - -	6	18	"Richard Warbrick," Bacton.	5	—	Wind at force 5. Weather hazy. Time, 7.45 a.m. Great difficulty and delay was caused by the total ignorance of the shipwrecked crew of the use of the apparatus, and five rockets were fired before communication was effected, but when this had been done they were all safely landed in the short space of 20 minutes.
7 Feb. -	Hartlepool, E. -	6	14	"Harrisons," between Heugh Light and new pier.	4	—	Wind at force 6. Time, 3.40 a.m. Weather dark with squalls of rain. Owing to the wreck being at too great a distance the first two rockets failed, and it was not until the apparatus had been with much difficulty carried to some outlying rocks that communication was effected, and the shipwrecked men rescued.

TABLE 4—*continued.*

Date of Service.	Name of Rocket Apparatus Station.	No of. Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives saved.	No. of Lives lost.	Particulars of the Service.
1880. 16 Feb. -	Peterhead -	6	26	"Augusta," 600 yards N. of Buchan Ness.	5	—	Wind at force 8. Weather overcast and hazy. Time, 1.35 p.m. A rocket line was thrown over the wreck, but the crew did not understand its use, and when every means to make them do so had been tried in vain one of the rocket party, Robert Oatley, gallantly, and at the risk of his own life, swam off to the vessel, instructed those on board how to use the apparatus and by its means they were all, five in number, safely landed, Oatley himself being the last to leave. For this brave service Oatley was awarded the Albert Medal of the second class, which was presented to him by the Queen herself.
1 Mar. -	Whitehaven -	—	Brigade	"James," North Shore, Whitehaven.	5	—	Wind at force 9. Weather showery. Time, 2.55 p.m. No rocket was fired, as the vessel came so close to shore that a line was thrown on board by hand, and communication having been effected in this way the shipwrecked crew were safely landed.

TABLE 5. LIST and PARTICULARS of the Occasions, during the Year ended 30th June 1880, on which the LIFE-SAVING APPARATUS was taken out on Service, and Life was saved by the Rocket Party, but by Means other than the Apparatus.

Date of Service.	Name of Rocket Apparatus Station.	No. of Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives saved.	No. of Lives lost.	Particulars of the Service.
1879. 1 July -	Bridge of Don -	4	19	"Nineveh," 1 mile N. of Donmouth.	1	—	Wind at force 7. Weather overcast. Time, 12.45 p.m. Several of the rocket party put off in a coble and took one man out of the wreck. The master, the only other person on board, refused to leave the vessel, but got on shore when the tide receded.
14 " -	Crail - -	1	18	"Annetta," Fifeness	3	—	Wind at force 6. Weather thick with rain. Time, 4.25 a.m. Communication was effected by the second rocket, and a boat was hauled off by the rocket line and saved the three men.

TABLE 5—*continued.*

Date of Service.	Name of Rocket Apparatus Station.	No. of Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives saved.	No. of Lives lost.	Particulars of the Service.
1879. 18 Oct.	Inverallochy	1	24	"Superb," Cairnbulg Brigs.	6	—	Wind at force 7. Weather thick with rain. Time, 10.10 p.m. Three rockets were fired, but owing to the distance of the wreck from shore no communication could be effected. Two boats were then launched and manned by certain of the rocket party, and the first boat which reached the stranded steamer succeeded in rescuing her crew and landing them safely at Cairnbulg.
2 Nov.	Sandlemere	5	11	"Flora," 1 mile N. of Tunstall.	5	—	Wind at force 6. Weather squally with rain. Time, 1.40 a.m. Communication was effected with the second rocket, but as the vessel was breaking up the crew launched their boat and having made the whip fast to it were hauled on shore by the rocket party.
2 Dec.	South Pier, Sunderland. Roker	6	Brigade	"Viking," Sunderland Bar.	—	—	Wind at force 7. Weather cloudy. Time, 8.45 p.m. Communication had been effected by both apparatus when a heavy swell drove the vessel over the bar. A hawser was then sent ashore and manned by the brigade who towed the leaking vessel into the harbour.

12 Feb. -	Porthcawl -	3	25	"Baltic," near Porthcawl.	6	—	Wind at force 4. Weather fine and clear. Time, 10 p.m. Two rocket lines were thrown over the vessel, but the crew who had taken refuge in the rigging took no notice of them, and after waiting a long time till the tide receded, the rocket party were able to reach the vessel by going through the surf up to their waists in water. When they got on board they found both master and mate drunk in their cabin, and they carried them ashore, together with the rest of the crew, four in number, who were nearly exhausted.

TABLE 6. LIST and PARTICULARS of the Occasions during the Year ended 30th June 1880, on which the LIFE-SAVING APPARATUS was taken out on Service and no Life was saved by the Rocket Party.

Date of Service.	Name of Rocket Apparatus Station.	No. of Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives lost.	Particulars of the Service.
1879. 20 July -	Rhosneiger -	2	10	"Zephyrus," entrance of Cymmeran River, Anglesea.	—	Communication was effected, but crew left in their own boat.
21 " -	Montrose - -	1	23	"Nooit Volmaakt," Annit Bank.	—	Communication was effected, but the crew refused to avail themselves of the rocket line, and the vessel was eventually got off into deep water with the aid of the lifeboat.
21 " -	Uzon - -	4	24	"Nooit Volmaakt," Annit Bank.	—	Apparatus not required. Vessel warped into deep water by lifeboat.
7 Sept. -	Flamborough -	5	25	"Mallard," S.S., ½ mile S. of Flamborough Head.	—	Communication was effected and tackle hauled on board, but as the lifeboat came up at the time no use was made of the apparatus.
7 " -	Reeth - -	12	5	"Charles W. Anderson," in danger off St. Catherine's Point.	—	Vessel escaped.
9 " -	Penrhyn - -	6	12	"Ellen," Llanymor Point.	—	Apparatus not used. Crew being rescued by lifeboat.

23 „ -	Newbiggin -	3	15	"Union T.," 1 mile north of Newbiggin Point.	—	Apparatus not used, the vessel being beyond range of the rockets. Crew rescued by lifeboat.
5 Oct. -	Whitburn -	2	23	"Czar," $\frac{1}{2}$ mile south of Souter Point.		Communication was effected with the first rocket, but crew did not avail themselves of the apparatus, remaining on board until two tugs came to their assistance.
7 „ -	Amlwch -	2	26	"Arabian" S.S., Bull Bay, Amlwch.	—	Apparatus not required. Vessel got off and put to sea
15 „ -	St. David's -	3	19	"Messenger," outside Ramsey Island.	—	Apparatus not required. Crew rescued by lifeboat.
17 „ -	Peel - -	—	19	"James," Peel -	—	Apparatus not required as the vessel's anchors held until a shift of wind enabled her to make the harbour.
17 „ -	Workington -	—	Brigade	"Solafide," North Beach, Workington.	—	Apparatus not required. Vessel assisted by a tug.
18 „ -	Fraserburgh -	6	16	"Superb," Cairnbulg	—	Apparatus not required. Crew rescued by rocket party from Inverallochy.
24 „ -	Carnsore -	1	15	Unknown vessel in danger off Carnsore Point.	—	Vessel escaped and put to sea.
27 „ -	Oyster Haven -	2	12	Unknown yacht, Barry's Head.	—	Apparatus not required. Vessel towed away by a tug.
2 Nov. -	Aldborough -	2	13	"Flora," Helston -	—	Apparatus not required. Crew rescued by rocket party from Sandlemere.
2 „ -	Amble, S. - -	4	20	"Neilson Taylor," Amble Bar.	—	Apparatus not required. Vessel got safely into harbour.
11 „ -	Groomsport -	13	4	"Charger," Ballyhome Bay.	—	Communication was effected, but the weather having moderated the crew remained on board.

TABLE 6—*continued.*

Date of Service.	Name of Rocket Apparatus Station.	No. of Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives lost.	Particulars of the Service.
1879. 12 Nov. -	Beadnel - -	3	24	"Trio," off North Sunderland.	—	Apparatus not required. Crew landed in their own boat.
15 „ -	Coatham - -	4	18	Unknown S.S. in danger.	—	Apparatus not required. Vessel escaped.
19 „ -	Lowestoft -	7	5	"Henrys," 150 yards S. of Lowestoft Harbour.	—	Communication was about to be effected when the vessel's cable parted, and she drove up on shore, enabling the crew to escape by wading through the surf.
20 „ -	Holmpton -	2	14	"Bertha," Withernsea.	—	Apparatus not required. Crew rescued by rocket party from Sandlemere.
20 „ -	South Pier, Sunderland.	7	Brigade	"Little Henry," ¼ mile south of South Pier.	—	Apparatus not required. Crew landed in their own boat.
22 „ -	Walmer - -	9	—	"India," ¼ mile north of Hope Point.	—	Apparatus not required. Vessel assisted by a tug.
24 „ -	Eyemouth - -	2	12	"Foam," south side of Eyemouth Harbour.	—	Apparatus not required. Vessel slipped her cable and put to sea.
30 „ -	Staithes - -	3	24	Unknown vessel reported in danger in Port Mulgrave Bay.	—	Vessel could not be found.

1 Dec. -	Gorleston - -	3	7	"Saucy Jack," north of Gorleston.	—	Communication was effected, but the crew did not avail themselves of the apparatus, but were landed by means of a hawser floated ashore with the assistance of the beachmen.
13 " -	Robin Hood's Bay	5	6	"Charlotte," North Cheek, Robin Hood's Bay.	—	Communication was effected by the first rocket, but crew did not avail themselves of the apparatus.
20 " -	Carnsore - -	1	19	"Chevreuil," off Carnsore Station.	—	Apparatus not available as vessel was beyond range of the rockets. Crew of 13 saved by lifeboat.
22 " -	Holmpton - -	2	9	"Magna Charta," Withernsea.	—	Apparatus not required. Vessel got off.
24 " -	Robin Hood's Bay	5	14	"Thorn," near Coastguard Station.	—	Apparatus not required. Crew remained on board until the tide receded and then walked ashore.
28 " -	Banff - - -	4	15	"Notre Dame," Macduff Harbour.	—	Apparatus not required. Vessel got safely into harbour.
1880. 14 Jan. -	Holyhead -	6	8	Unknown S.S. in danger in Penrhos Bay.	—	Vessel escaped.
15 " -	Peterhead - -	7	13	"Mary Ann," off Peterhead.	—	Apparatus not required. Crew left the vessel in their own boat and were picked up by a tug.
18 " -	Happisburgh -	4	17	"Thomas Turnbull," off Hasbro'.	—	A rocket was fired over the wreck but communication was not effected. Vessel was found to be a derelict.
21 " -	Donna Nook -	6	4	"Calvilla," S.S., off Donna Nook Beacon.	—	Apparatus not used. Vessel being too far off.
24 " -	Whitehaven	—	Brigade	"Zingara," Scarr, Nethertown.	—	Apparatus not required. Crew landed in their own boat.
29 " -	Holyhead -	6	8	"Belle of the Plym," outside Holyhead Breakwater.	—	Apparatus not used. Vessel towed off by a tug.

TABLE 6—*continued.*

Date of Service.	Name of Rocket Apparatus Station.	No. of Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives lost.	Particulars of the Service.
1880. 1 Feb. -	Fraserburgh -	2	6	"Lewisman," Cairnbulg.	—	Apparatus not taken out. Vessel got off and taken into harbour.
6 „ -	Holyhead -	6	13	"Kate," Holyhead Breakwater.	—	Apparatus not required. Vessel towed off by a tug.
8 „ -	Easington -	6	13	Unknown smack in danger off Easington.	—	Communication was effected, but a sudden change in the wind taking place the vessel got off.
9 „ -	Charlestown -	6	10	"Jane Ellen," Charlestown Beach.	All hands.	Three rockets were fired, but it was subsequently ascertained that the crew had left the vessel in their own boat and were all lost, the boat being found at daylight under the cliffs.
9 „ -	Mount Batten -	12	15	"Hankow," S.S., in danger near Plymouth Breakwater.	—	Apparatus not required. Vessel assisted into the sound by tugs.
9 „ -	Ramsey - -	—	23	"John Wesley"	—	Apparatus not required. Crew taken off by lifeboat.
9 „ -	Walmer - -	7	—	"Anne," Hope Point	—	Apparatus not required. Crew left in their own boat.
11 „ -	Old Head -	1	17	Unknown vessel in danger in Courtmacsherry Bay.	—	Vessel could not be found, but is supposed to have escaped owing to a change in the wind.
13 „ -	Roker - -	7	Brigade	"Rapid," White Sand Rocks.	—	Apparatus not required. Crew rescued by a pilot coble.

14 „ -	Drumore - -	4	11	"Comet," Drumore	—	Apparatus not required. Vessel was driven up high on the beach, and crew remained on board until the tide receded.
15 „ -	Middleton -	6	23	"Surprize," Middleton Sands.	—	Communication was effected, but crew refused to leave and remained on board until low water.
16 „ -	Arbroath - -	2	20	"Neptunes," Auchmithie."	8	Vessel broke up in 15 minutes from time of striking, and before the arrival of the rocket apparatus, only one man escaping out of a crew of nine.
16 „ -	Hartlepool -	6	24	"Eglantine," between old and new piers.	—	Apparatus not required, vessel driven over the rocks into deep water.
16 „ -	Rickham - -	7	15	"Eugene," 400 yards W. of Rickham Sands.	All hands.	Commuication was effected, and a man who was apparently the sole survivor of the crew was being hauled ashore by the rocket line when a heavy sea broke over the rocks and the seamen, together with McClements, one of the party engaged in the service, were swept away and lost their lives. Keast, another of the party engaged, was also carried away, and only rescued with much difficulty. The Board of Trade awarded a sum of 1*l.* in addition to the usual allowances to Samuel Keast for his praiseworthy service on this occasion, and provision has also been made for the child of McClements. *See* Rewards, &c., p. 8.
16 „	Scarborough -	7	10	Unknown fishing vessel in danger.	—	Vessel escaped.
16 „ -	South Shields -	—	Brigade	"Thomas and Elizabeth," South Pier.	6	A rocket was fired over the wreck, but before the crew could avail themselves of the line the foremast went, followed by the mainmast, and the vessel in a few minutes broke up, and all hands were lost.
17 „ -	Orfordness -	1	9	"Johannes," Orfordness Beach.	—	Apparatus not required. Vessel having driven close to beach.

TABLE 6—*continued.*

Date of Service.	Name of Rocket Apparatus Station.	No. of Coast-guard Men engaged.	No. of other Persons engaged.	Name of Vessel, and Place of Casualty.	No. of Lives lost.	Particulars of the Service.
1880. 19 Feb. -	Langton - -	6	15	Unknown vessels in dangerous position off Langton.	—	Vessels escaped.
19 „ -	Wyke - -	19	—	Unknown vessels in dangerous position off Wyke.	—	Apparatus not required, as wind abated and vessels escaped.
24 „ -	Fair Isle - -	—	39	Unknown Norwegian schooner N. end of Fair Isle.	All hands.	Vessel drove ashore during the night and all hands lost. The lifeboat was manned and sent to the scene of wreck, and a land party despatched at the same time with cliff ladders, but no survivors could be found.
26 „ -	Burghead - -	4	18	"Polar Star," Hopeman Harbour.	—	Apparatus not required, crew being rescued by persons assembled on the quays.
17 Mar. -	Annalong -	5	18	"Sally and Ann," near Annalong.	—	Apparatus not required, crew having waded ashore before the arrival of the rocket party.
21 „ -	Wicklow - -	6	8	"Newhaven," in danger near Brides Head.	—	Vessel escaped.
23 „ -	Budehaven -	4	12	"Bee," Summerlease Point, Bude.	—	Apparatus not required. Crew remained safely on board.
31 „ -	Weymouth - Wyke - -	11 14	— —	"Band of Hope," off Chesil Beach.	—	Apparatus not required. Vessel assisted by a tug.

2 April -	Montrose -	1	23	"Edith," in dangerous position at the entrance of Montrose Harbour.	—	Apparatus not required. Vessel got safely into harbour.
6 " -	Ilfracombe -	5	—	Two men in dangerous position in White Pebble Cove.	—	The cliff ladders were taken to the assistance of two men, who were in a dangerous position on a ledge of cliff, but they could not be prevailed upon to move until daylight, when they went down the cliff to the beach, the tide having receded.
9 " -	Happisburgh -	5	15	"Rival," Ostend Gap, Hasbro'.	—	Vessel beyond range of the rockets. Crew rescued by the lifeboat.
19 " -	St. David's -	2	21	"Maria Fredrickstadt," St. Bride's Bay.	—	Apparatus not used. Vessel towed off by a tug.
4 May -	Lizard - -	10	12	Unknown vessel on Dale Rocks, Lizard.	—	Apparatus not required. Vessel got off before the arrival of the rocket party.

Government Documents
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